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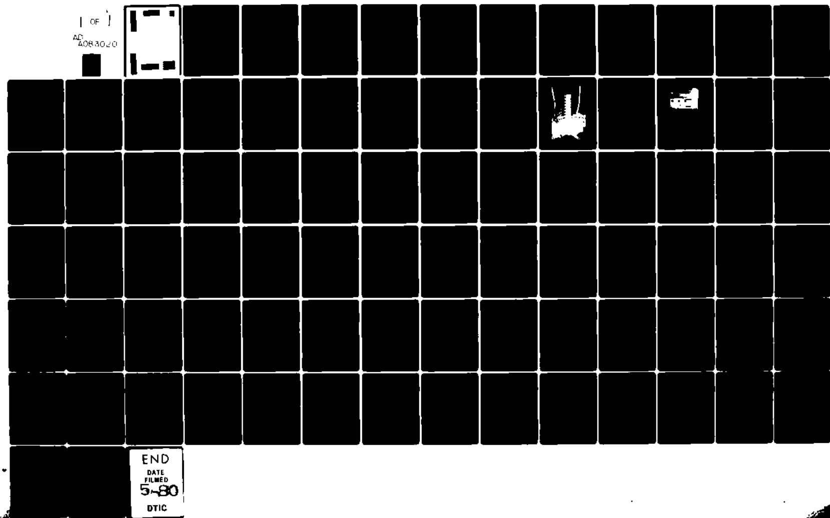

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Removal of Grease from Secondary Effluent by Granular Medium Filtration

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Final Report 24 Mar 80

A thesis submitted to the University of California at Davis, in Davis California in partial fulfillment of the requirements for the degree of Masters of Science in Engineering

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The presence of grease in the effluent of secondary wastewater treatment plants is a source of pollution. As such, its removal is desireable. The ability of sand filters, as used in tertiary treatment, to remove grease from secondary effluent is examined in this study.

A mixture of secondary effluent and oleic acid, which was

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added to enhance the grease content of the effluent, was filtered through three high pressure sand filters. During the first stage of the experiment the flowrate through the filters was held constant and the size of the medium was varied. During the second stage the medium size was constant and the flowrate was varied. Samples of the filter influent and effluent were taken and analyzed using a Total Carbon analyzer.

It was concluded after analysis of the data, that neither medium size or filtration flowrate had a significant effect on the removal of grease by the sand filters. Initial differences were noted, however after 1-1/2 hours of operation the removals observed were nearly identical, regardless of medium size or flowrate. After the initial diferences, the grease removal was on the order of 10 percent or less.

The removal of grease, from secondary effluent with grease concentrations less than 50 mg/l, by filtration through a sand medium with a size range of 0.27-0.47 mm at flowrates ranging from 1.2-5.0 gpm/ft^2 is limited. In such cases, the removal of 10 percent of the grease present can be expected. It is expected that the filtration of effluents with higher grease concentrations such as those in cold weather regions, will be more successful.

Removal of Grease from Secondary Effluent by Granular Medium Filtration

By

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1. INTRODUCTION

Secondary treatment is used to remove the organic material present in raw wastewater. Grease and oil represent a significant portion of the organic matter. Because they are insoluble in water, many of the grease and oil compounds resist treatment and are discharged in the plant effluent (12).

Grease and oil are also referred to as lipids. The terms are used synonomously and refer to hydrocarbons, glycerides, sterols, fatty acids, and compound lipids such as phospholids (12). Grease and oil are also referred to as freon extractables because of their solubility in the solvent freon. In this report the term grease will be used.

Grease discharged from secondary wastewater treatment plants is a source of pollution. Even small quantities of grease can have a significant impact upon the receiving waters. Small amounts of grease can cover large areas of the receiving stream surface, causing unsightly films (14, 16). These films can interfere with the transfer of oxygen into the receiving water thereby damaging fish and plant life (14, 16). The continued addition of these compounds to the stream can lead to unsightly formations at the point of discharge and along the banks (11, 14). If the waters of the stream are later used as a source of drinking water, grease can impart a taste and an unpleasant odor (14). If the waters are to be used for irrigation, the grease present can clog the soil pores, resulting in the formation of a barrier to the transport of oxygen and water into the soil (14).

The use of chlorine to disinfect treated wastewater is common. The dosage of chlorine required to accomplish grease removal from the effluent of municipal treatment plants is in the range of 2-10 mg/l (16). The addition of

chlorine adds another dimension to the problem. Arquello et al (1) state that the addition of chlorine to waters containing organic matter enhances the formation of trihalomethanes, which are suspected cancer causing agents.

For the reasons cited above, the removal of grease from secondary effluent is desirable. This removal can be accomplished by improving the efficiency of the secondary treatment processes or by tertiary treatment. Several tertiary treatment processes are in use. One such process which has received increased use over the past decade is granular filtration. Filtration is simple and relatively low in cost and can be used to remove particulate and colloidal matter, to increase the removal of constituents such as BOD, COD, bacteria, virus, heavy metals, and to increase treatment plant reliability (4). Filtration may also be effective in the removal of grease.

Purpose of Study

The purpose of this study is to investigate the effectiveness of sand filtration for the removal of grease from secondary effluent.

Objectives

The size of the filter material used and the filtration flowrate are among the most important process variables of filtration (16). Therefore, the specific objectives of this study are:

(1) To determine an optimum size of filtering medium for the removal of grease.

(2) To determine an optimum filtration flowrate for the removal of grease when using the optimum sand size.

2. BACKGROUND

During the preparation and conduct of this study a review of available literature was conducted to obtain information on any previous studies dealing wtih the removal of grease from secondary effluent by sand filtration. Also of interest were reports dealing with the characteristics of secondary effluent and on the removal mechanisms that may be operative during the filtration of secondary effluent.

Prior Filtration Studies

Unfortunately, little study of the removal of grease using sand filters has taken place. Studies by members of the petroleum industry were the only references found in which the removal of grease by sand filters are addressed (2, 9, 10).

Dual medium filter performance was studied by the British Petroleum Oil Company over a three year period (2). In an effort to reduce the grease and oil concentration of refinery wastes, the wastes were passed through dual medium filters after the initial separation process. An average grease removal of 60 percent was observed during the study (2). Imperial Oil Ltd. of Canada also conducted investigations of the filtration of separator effluent by dual medium filtration. They reported a 75 - 79 percent oil removal rate (9). Envirotech Corporation compared the results obtained from pilot studies conducted using single medium sand filters with the results from full scale operations. No quantitative oil removal results were presented, however it was reported that effective oil removal was accomplished (10). Additionally, comparison of pilot plant to full scale plant data based on turbidity resulted in a correlation the

authors describe as "precise" (10). Based on these reports there is reason to believe that sand filters are effective in the removal of grease from secondary effluent.

Grease in Secondary Effluent

The grease and organic content of secondary effluent have been the subject of several investigations (3, 11, 12, 14, 17, 19, 28). Even so, knowledge of the composition of wastewater effluents remains sparse. In 1960, Painter, Viney and Bywaters (17) were able to identify only 32 percent of the organic carbon compounds in secondary effluent. Similarly, Bunch, Barth and Ettinger (3) were able to identify 35 percent of the chemically oxidizable material in studies conducted in 1961.

Domestic and industrial discharges are primary sources of grease in wastewater. Other sources are automotive wastes and rainfall runoff. Young (28) characterized the grease in sewage in three ways: (1) by polarity, (2) by biodegradability, and (3) by physical characteristics. Polar greases are normally of animal and vegetable origin and are usually biodegradable. The nonpolar greases are usually of petroleum or mineral origin. Loehr and Kukar (12) report the existence of grease in three forms, (1) free or floatable, (2) attached to solids or non-floatable and (3) semi-colloidal. Using thin layer chromatography (TLC) Loehr and de Navarra (11) went one step further and characterized the grease in wastewater by predominate classes. The classes, in order of predominance, are fatty acids, triglycerides, hydrocarbons, compound lipids, sterol esters, and sterols.

As much as 45 percent of the total grease may be removed during primary treatment (11). Those greases present as free or floatable, rise to the surface and are skimmed off. Because this method of treatment is physical rather than

biological, the classes of greases present and their order of predominance remain the same as those of raw wastewater.

In secondary treatment the organic matter present is metabolized by microorganisms. Although most greases remaining after primary treatment should be biodegradable, many resist oxidation because of their low solubility in water. Those greases most susceptible to oxidation are polar in nature and the extent of the oxidation depends on the contact time with the microorganisms. The greases discharged from the secondary treatment process then may be characterized as non-polar material and polar grease which is not fully oxidized (28). The greases are discharged as colloidal matter, in the dissolved state or as matter attached to suspended particles (5).

During secondary treatment the predominate classes of grease change (11, 12). The predominate classes become hydrocarbons, compound lipids, fatty acids, triglycerides, sterol esters and sterols (11). Classification of the hydrocarbons and compound lipids by specific compound has not been accomplished. Fatty acids have been identified in great detail. The presence of carbon compounds of 16, 18, and 20 carbon atom chains has been verified using TLC analysis (5, 12). Fatty acids of this composition are oleic, stearic, linoleic, arachridic, lauric, and palmitic, and are the major fatty acids in wastewater.

Loehr and Roth (13) report that palmitic, stearic, and oleic acids usually make up over 80 percent of the fatty acids in wastewater. The effluent of three wastewater treatment plants in Rhode Island were studied by Farrington and Quinn (5). They found that of the fatty acids present in municipal secondary effluent, unsaturated fatty acids predominate. Using TLC they also found that the most abundant fatty acid had an 18:1 carbon atom structure. The unsaturated fatty acid with an 18:1 carbon structure is oleic acid.

Rickert and Hunter (19) using total carbon analysis to characterize secondary effluent, report that 69 percent of the TOC in secondary effluent is

soluable. Only 5 percent of the soluble solids fraction was organic. The remaining 31 percent was found to be colloidal.

Removal Mechanisms

During the operation of a filter several mechanisms are responsible for the removal of particulate matter from the filtrate. A list and brief description of each is given in Table 1. For a detailed description of each the reader is directed to References 16 and 26.

The grease removal capabilities of these mechanisms have not been demonstrated clearly. As discussed earlier, significant removals were observed during tests conducted by the petroleum industry (2, 9, 10). However some investigators feel that granular filters should not be expected to remove grease (15). A brief discussion of those mechanisms that may affect the removal of grease follows.

Considering the removal mechanisms of Table 1 and the character of the greases in secondary effluent, it is clear that only a few mechanisms are capable of removing grease. The most probable are straining, interception, adsorption and adhesion.

Straining - During filtration straining is the principal method of solids removal (26). Straining has two components, mechanical straining and chance contact. Removal of particles too large to pass through the pore spaces of the medium is referred to as mechanical straining. The term chance contact is used when refering to that material which accumulates within the pore spaces of the medium or on particles that have already been removed. As the solid particles are removed by straining, the grease that is attached to the solids will also be removed. Such removal depends upon the strength of the bond holding the grease to the solid and the filtration flowrate. If the attraction is weak

TABLE 1: Removal Mechanisms Operative In Granular Medium Filters[a]

Mechanism	Description
1. Straining	
a. Mechanical	Particles larger than the pore space of the filtering medium are strained out mechanically
b. Chance contact	Particles smaller than the pore space are trapped within the filter by chance contact
2. Sedimentation	Particles settle on the filtering medium within the filter
3. Impaction	Heavy particles will not follow the flow streamlines
4. Interception	Many particles that move along in the streamline are removed when they come in contact with the surface of the filtering medium
5. Adhesion	Flocculant particles become attached to the surface of the filtering medium as they pass by. Because of the force of the flowing water, some material is sheared away before it becomes firmly attached and is pushed deeper into the filter bed. As the bed becomes clogged, the surface shear force increases to a point at which no additional material can be removed. Some material may break through the bottom of the filter, causing the sudden appearance of turbidity in the effluent
6. Chemical adsorption	
a. Bonding	
b. Chemical interaction	
7. Physical adsorption	Once a particle has been brought in contact with the surface of the filtering medium or with other particles, either one of these mechanisms, or both, may be responsible for hold it there
a. Electrostatic forces	
b. Electrokinetic forces	
c. van der Waals forces	
8. Flocculation	Large particles overtake smaller particles, join them, and form still larger particles. These particles are then removed by one or more of the above removal mechanisms (1 through 5)
9. Biological growth	Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms (1 through 5)

a Source: Ref (16)

or the flowrate too great, the grease may be stripped from the particle and reenter the liquid.

Interception - Interception involves the particles traveling along streamlines that pass close enough to the sand grains for contact to occur (26). Such particles are removed when the contact occurs. Grease, in any form present in secondary effluent, may be removed in this manner. As in straining, the success of such removal will depend on the strength of the grease attachment to the sand grain.

Adsorption - Adsorption of material to the medium during filtration should also be effective in grease removal. Like straining, adsorption has two components. Chemical adsorption occurs as a result of chemical interaction and bonding. For instance, colloids, as found in secondary effluent, are destabilized by the presence of higher charged counter-ions (20). Such chemical interaction may occur: however, it is not expected to have a major effect on grease removal. Physical adsorption is a result of the forces of molecular attraction, such as van der Waals forces, and electrostatic and electrokinetic forces. Because a large part of the greases present are hydrophobic colloids and as such carry an electrical charge, it is probably that physical adsorption will play a significant role in their removal.

Adhesion - Another probable removal mechanism for grease is adhesion. Molecular forces and electrostatic forces cause particles to adhere to one another and to the medium (26). As with adsorption, the charged nature of the colloidal matter suggests that adhesion will have an effect upon grease removal.

Expected Removal - As discussed earlier, the grease in secondary effluent is characterized as colloidal, soluble, and attached to solids. The soluble portion of the effluent, which comprises 69 percent of the carbon present (19), is not expected to be removed during filtration. The remaining colloidal carbon will

be affected by straining, interception, adsorption and adhesion. However, the amount of colloidal grease represented in the remaining 31 percent of the carbon is small and it is expected that grease removals will be on the order of 15 to 20 percent.

3. METHODS AND PROCEDURES

The development of the experimental apparatus and the analytical techniques employed required four months of testing and alteration. The apparatus and the techniques comprising the final experimental system are discussed in this section.

Experimental Apparatus

The filtration system used is depicted in Figure 1. The primary components are three high pressure filters filled with sand and a chemical feed mechanism. Secondary effluent from the University of California at Davis (UCD) Wastewater Treatment Plant was pumped, using a submersible pump, from the effluent channel of the secondary clarifier to the filters. To simulate the presence of grease, the influent to the filters was injected with measured amounts of oleic acid. (The reason for injecting the oleic acid is discussed in Appendix A.) The feed solution was then split, by means of a manifold, into three components. Each component passed through a Burkes 1/4 HP centrifugal pump and entered the filters at approximately 45 lb/in^2 (psi). After filtration the effluent was collected and returned to the primary clarifier.

High Pressure Filter - The two components of primary interest in each filter are the filter and the filter medium. The filter (see Figure 2) consists of a plexiglass column, forty eight inches tall and three inches in diameter, held in compression between the top plate and the underdrain by four stainless steel rods. The plexiglass column is made up of eleven sections. Each section has a sampling port and a pressure port. The base section is constructed of one-half inch plexiglass with one-quarter inch diameter holes drilled through it. The

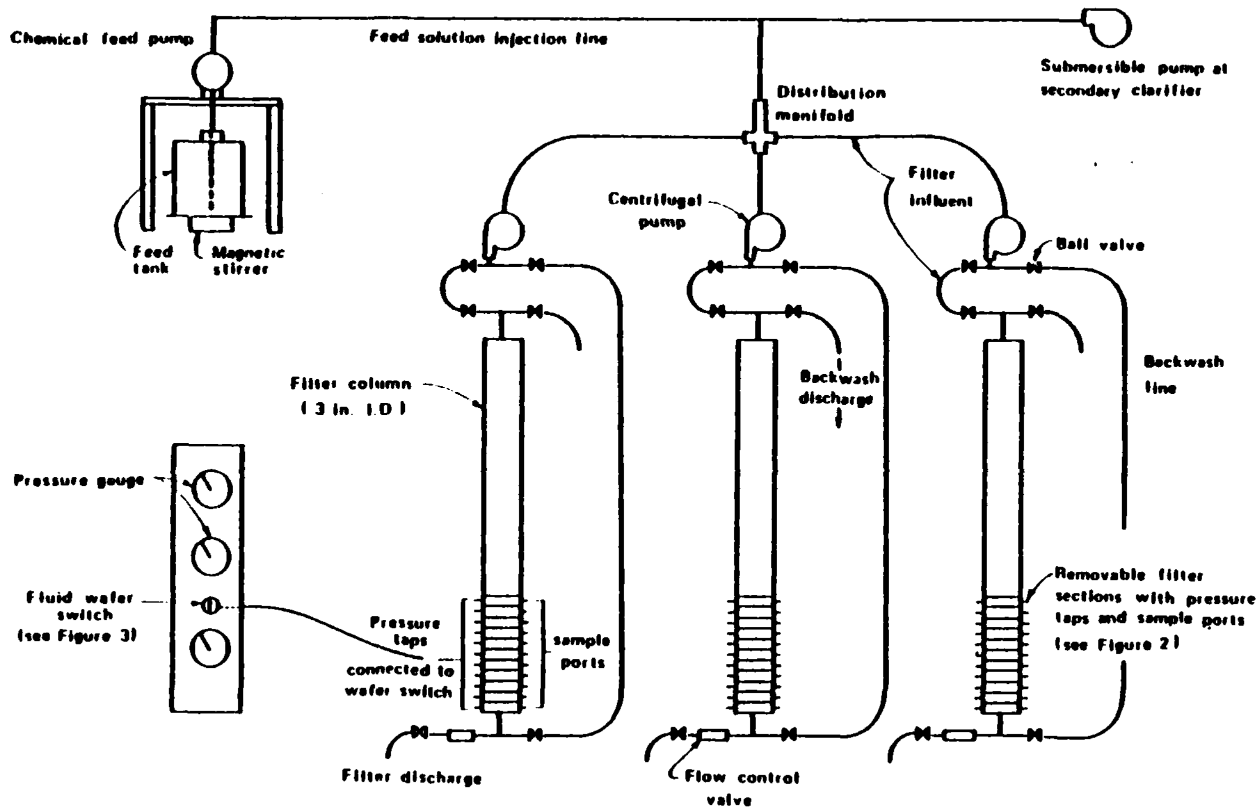


Figure 1: Schematic of Experimental Filtration System

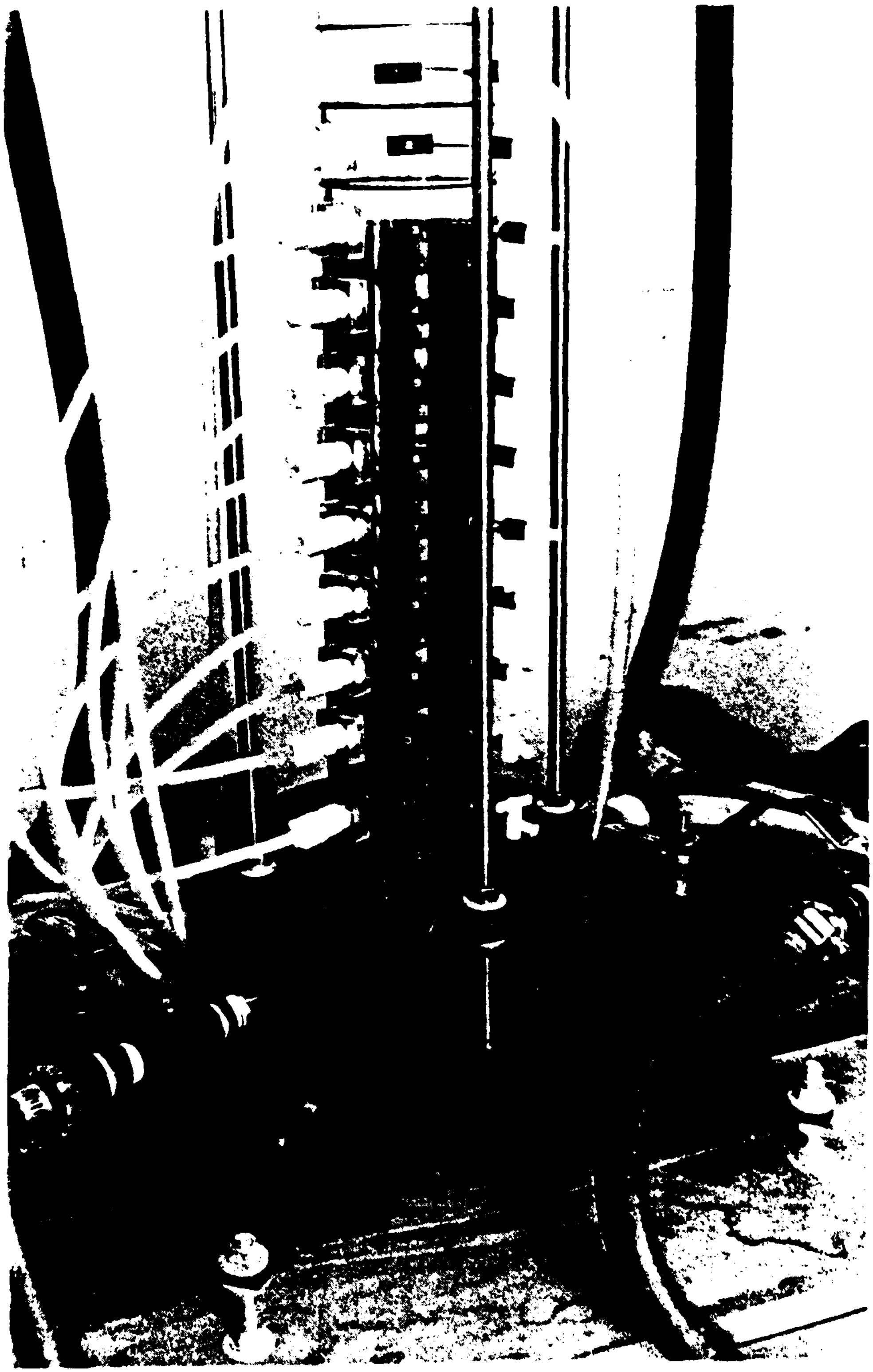


Figure 2: Photograph of an Experimental Filter Showing Removable Filter Sections, Pressure Taps, and Sample Ports

base is covered by a screen which has been sized to prevent the loss of the filter medium.

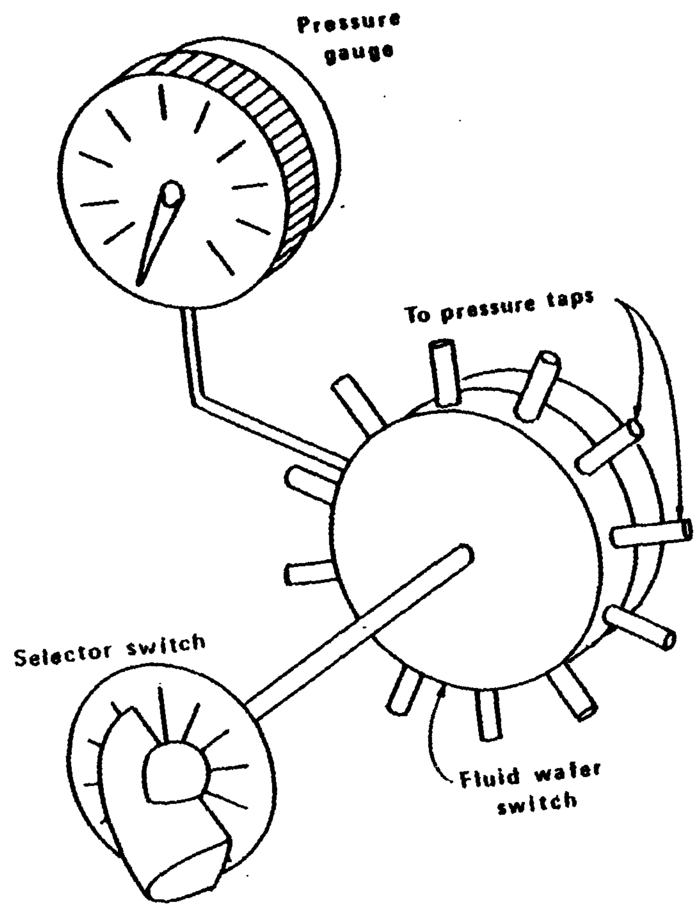
Sixteen gauge disposable hypodermic needles were used as sampling devices. Holes were drilled in the side of the sections and the needles were inserted and glued into position. To open and close the sample port, one-way stopcocks with male luer lock adapters, obtained from Pharmaseal Inc., were used.

Pressure ports were used to monitor the headloss across the filter bed. They were connected using polyethylene tubing to a fluid wafer switch. The fluid wafer switch is a one-pole twelve throw switch (model W01) produced by Scanivalve Inc of San Diego, California. (see Figure 3) The wafer switch was in turn connected to a pressure gauge.

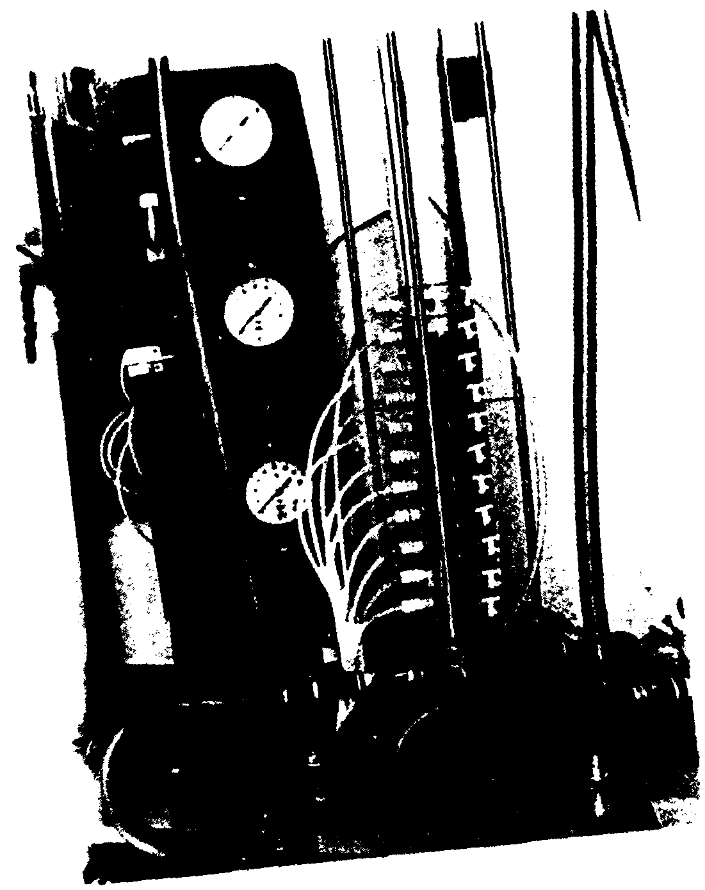
The flow through each filter was controlled with a Dole flow control valve obtained from the Dole Valve Company of Morton Grove, Illinois. The valve was placed at the exit of the underdrain assembly. The flowrates selected for this study were 0.06, 0.125, and 0.25 gallons per minute (gpm). The corresponding filtration flowrates are 1.2, 2.5, and 5.0 gpm.ft^2 (48.9, 101.8, and 203.7 lpm/m^2. (see Appendix B) These flowrates were selected because they represent typical rates at which filters would be expected to operate in the field (4).

Fundamental to the filtration process is the filter medium to be used. For these studies the filter bed consisted of sand, twelve inches in depth. The sand, obtained from Lone Star Industries, was custom blended by the manufacturer to insure size and uniformity.

A standard sieve analysis was conducted to check the size and uniformity specifications. The sand sizes were checked and found to be 0.27, 0.34, and 0.47 mm using routine sieving techniques with US Standard sieves. (see Appendix C) The coefficients of uniformity (Cu) are 1.30, 1.40, and 1.47 respectively.



(a) Fluid wafer switch



(b) Pressure gauge control panel

Figure 3: Pressure Sensing Apparatus

The sand is characterized as being sharp and angular in shape, as discussed by Tchobanoglous (26).

Experimentation was to be conducted at several local wastewater treatment plants, so the filters were mounted in a Dodge van for mobility. Two local treatment plants were visited, and after analysis of the samples taken it was concluded that insufficient amounts of grease were present for the continuation of the study. A detailed description of these preliminary studies is presented in Appendix A.

Young offers an explanation for the low grease content of the effluents tested. He reports (28) that climate is a significant factor in the ability of activated sludge plants to remove grease and oil. He found that plants in Southern California received higher influent grease concentrations and provided better effluent quality than plants located in the Northeastern and Northwestern United States.

Based on the preliminary results and Young's observations it was decided to dose the filters with a synthetic feed. After consideration of the characteristics of secondary effluents, as discussed earlier, oleic acid was chosen as a suitable feed substance.

The decision to use a synthetic feed precipitated two major changes in the experimental program. Because it was no longer necessary to move the filters from one plant to another, the filters were located premanently at the UCD Wastewater Treatment Plant. Additionally, some method of adding the oleic acid to the secondary effluent had to be developed. The feeding apparatus is discussed in the next section.

Feeding Apparatus - The feed apparatus used is depicted in Figure 1. Development of the system is described in Appendix A. To inject the oleic acid into the secondary effluent a Liquid Metronics Model A131 Chemical Feed

Pump was used. The pump is a diaphragm pump with a variable speed capability. Included with the pump is a foot valve for use in the feed tank and an anti-syphon injection valve which was placed in the line ten feet in front of the manifold so that the feed solution would have a sufficient amount of time to mix with the secondary effluent.

To make the feed solution 25 gms of oleic acid were emulsified using 50 gms of detergent mixed in five gallons of water. The detergent used was Dynamo, a liquid clothes washing detergent emulsified with 50 gms of soap mixed in five gallons of water. A five gallon container was used to hold the feed solution, which was mixed continuously with a magnetic stirrer. The solution was metered into the flow at a rate of 0.052 l/min. This resulted in an approximate dosage of 20 mg/l to each filter. (see Appendix B)

Analytical Procedures

Two analytical techniques were used to ascertain the amounts of oleic acid present, the wet extraction technique and total carbon analysis.

Wet Extraction Technique - The partition-gravimetric method for the determination of greases and oil as outlined in the 14th edition of Standard Methods for the Examination of Water and Wastewater (22) was employed. One liter samples were extracted three times using 35 ml aliquots of 1, 1, 2-trichloro-1,2,2-triflouroethane (freon). The freon was then collected in a 250 ml flask and distilled away. The residue constitutes the grease and oil extracted from the sample.

Several difficulties were encountered using this test that ultimately led to the selection of another method. Samples were collected and stored in one liter bottles. When transferred to the separatory funnel, the sample was washed with freon, however it was impossible to be sure that all of the grease had been removed from the inside of the bottle.

It was noted that a large portion of the suspended solids did not remain in homogeneous solution during the extraction, but formed a large layer of cloudy matter at the freon-water interface. It was observed that the greater the concentration of suspended solids the larger the layer at the interface. When the freon was drained from the separatory funnel the cloudy matter was trapped on the sodium sulfate used to remove any water present in the freon. The nature of the material within this layer is unknown, and may represent a large loss of freon extractable material.

Taras and Blum (25) report that the use of sodium chloride can enhance the extraction process. They saturated samples with as much as 300 gms/l of sodium chloride and observed a marked increase in oil yield. In an attempt to increase the grease recovery from samples taken during this experiment, sodium chloride was added during the extraction process. A marked increase in grease recovery was not noticed. In several of the samples white crystals formed in the flasks during the distillation of the freon rendering the results worthless. Perhaps an excess of sodium chloride was used in these samples and affected the results. Taras and Blum (25) indicate that freon, as a solvent, is amenable to interference from sulfur. This interference is manifested in the formation of tiny white crystals. The chance occurrance of this interference is an additional deterent to the use of the freon extraction.

The accuracy of the test is also suspect. The residue is collected in a 250 ml flask, which weighs approximately 110 grams. An accumulation of grease representing 10 mg/l would be measured as a before and after weight difference of 0.01 grams. A difference of 0.005 grams can be extremely significant to the test results. The weight of the flask could vary as much as 0.005 grams as a result of the heating, cooling and immersion in a hot water bath, which is required. It was not uncommon to observe changes of this magnitude in the flasks tested as blanks.

Total Organic Carbon - The variability of the extraction method necessitated the selection of another analytical technique. The total organic carbon (TOC) analysis was selected. The analysis is accomplished using a machine, in this case a Dohrman 50 S Carbon Analyzer, which offers several advantages. Because the analysis is automated, the opportunity for the experiment to influence the results is reduced. Speed and accuracy are two more benefits of this method. A freon extraction required at least four hours to complete. In comparison, the TOC machine operates on a six minute cycle which saves a great deal of time.

Sampling Methods and Storage - Samples were collected in 30 ml biological culture tubes. The tubes were washed before the samples were collected. To collect a sample the one-way stopcocks were opened and allowed to run for a short time. The collection tubes were rinsed again and the samples were taken. The samples were acidified immediately using concentrated hydrochloric acid and were placed under refrigeration until tested. With the exception of two samples, all were tested within two weeks of collection.

4. RESULTS

To acomplish the stated objectives of this study the necessary field experiments were conducted in two stages. In the first stage studies, the filtration flowrate was held constant at 5 gpm/ft^2 (203.7 lpm/m^2), and the size of the filter was varied. The purpose of these studies was to compare the grease removal through each medium and to select the most effective medium size. In stage two, each filter was filled with a medium of the size selected in the first stage and the filtration flowrate was varied. From an analysis of the data obtained during the second stage of the experiments it should be possible to select an optimum filtration flowrate.

During all phases of the experiment the feed mixture passing through each filter contained secondary effluent, soap, and oleic acid. An investigation of the effects of the soap and the secondary effluent was necessary so that these effects could be compensated for during the analysis of the grease removal.

The results of the two stages of testing plus the investigation of the effects of the soap mixture and the secondary effluent are presented and discussed in this section.

Effect of the Secondary Effluent

To determine the relationship between the filtration of secondary effluent and the removal of TOC, a controlled experiment was conducted. Secondary effluent was filtered and samples of the influent and effluent to the filters were analyzed. The results of the analysis are presented in Table 2. The results of each run and a summary curve are depicted in Figure 4. The principal conclusion derived from these results is that the removal of TOC from secondary

TABLE 2: Percent TOC Removed From Secondary Effluent by Filtration[a]

Time from start, hr	TOC removed, % Filter 1	Filter 2	Filter 3
1.50	10.4	16.5	13.1
2.75	21.6	---	12.0
5.00	17.2	21.5	8.6

[a]December 8, 1979

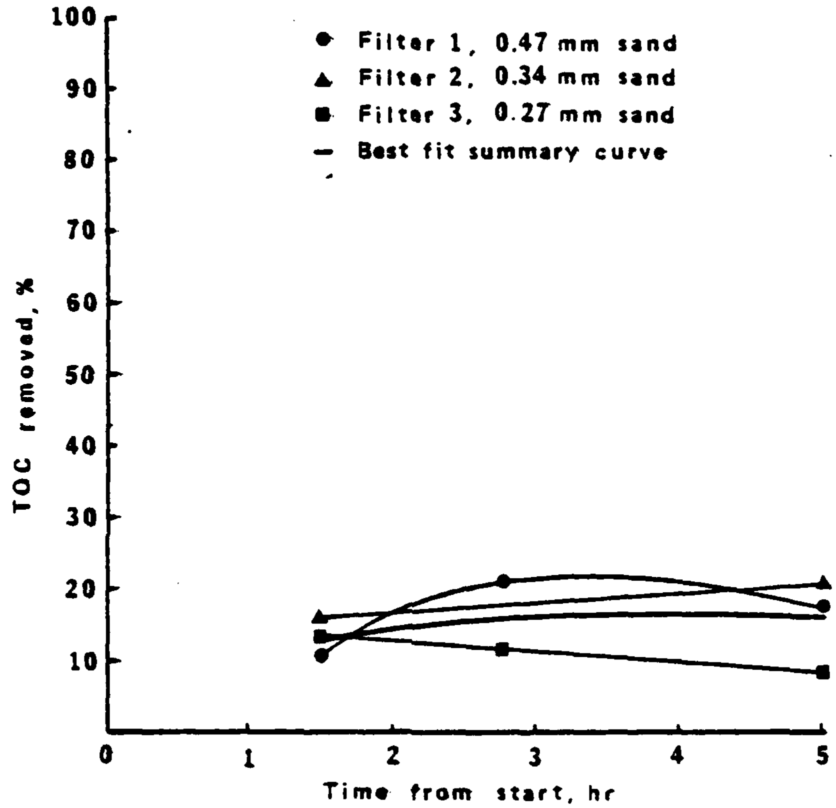


Figure 4: TOC Removed from Secondary Effluent by Filtration Versus Time

effluent by filtration is essentially constant. As a result, no compensation will be necessary during the analysis of the grease removal by filtration.

Effect of the Detergent

As with the secondary effluent, it was also necesary to determine what effect the addition of detergent to the feed mixture would have on the filtration process. To ascertain this effect two experiments in which a mixture of secondary effluent and detergent was filtered were conducted. The results are presented in Table 3 and Figures 5, 6, and 7 for filters 1, 2, and 3 respectively. A composite of all three summary curves is given in Figure 8.

The results, as represented in Figures 5, 6, and 7, are similar in pattern and magnitude. The pattern is one of a general, however slight, decrease in removal. The magnitude of the removals increases as the size of the medium decreases. (Figure 8) However, these increases are small, in the range of 5-7 percent. It is evident from a comparison of Figures 4 and 8 that the addition of detergent inhibits the TOC removal ability of the filters. The removals obtained with detergent present are approximately 50 percent less than the removals obtained in the absence of the soap.

As with the filtration of the secondary effluent alone, the effect of the detergent addition is constant over the length of the filter run. Because the effect is constant, it will not be necessary to compensate for it during the grease analysis.

Determination of an Optimum Size of Filter Medium

During this experiment the flowrate was held constant at 5 gpm/ft^2 (203.7 lpm/m^2) and three different medium sizes were used. The sand sizes were 0.47, 0.34 and 0.27 mm in filters 1, 2 and 3 respectively. To insure that the results obtained were consistant and comparable the experiment was repeated four

TABLE 3: Percent TOC Removed From A Mixture of Detergent and Secondary Effluent by Filtration

Date	Time from	TOC removed %		
	start, hr	Filter 1	Filter 2	Filter 3
	2.00	5.8	5.7	18.9
8 Jan 80	3.25	3.0	9.9	5.5
	4.50	8.0	7.5	11.9
	0.25	10.2	8.3	12.4
9 Jan 80	1.50	5.2	9.9	8.9
	3.00	4.9	6.1	11.1
	5.00	2.3	2.3	1.4

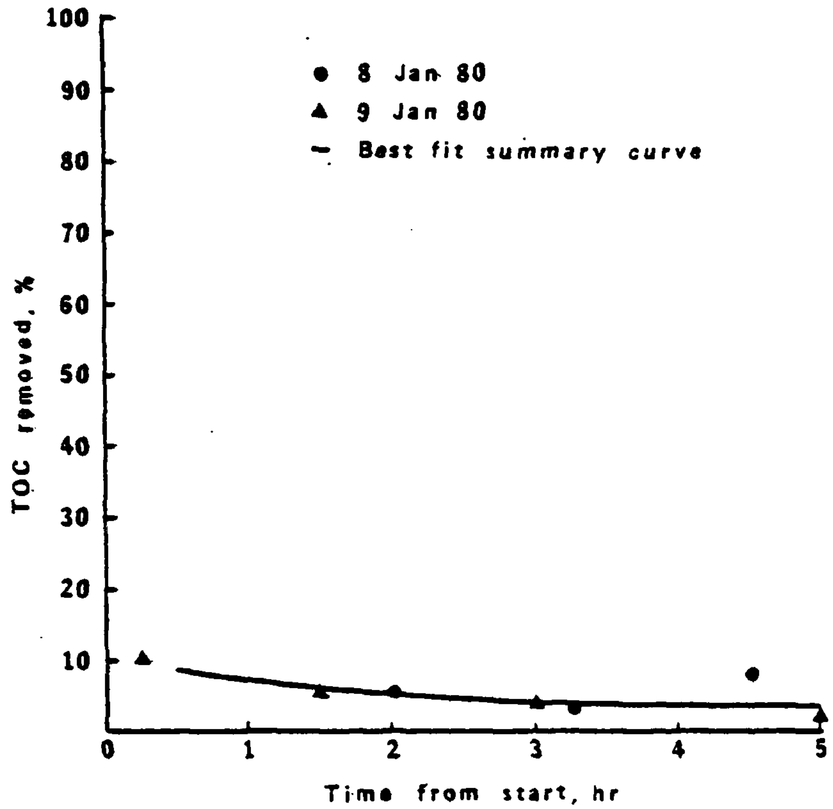


Figure 5: TOC Removed from a Mixture of Detergent and Secondary Effluent by Filtration Through Filter 1 Versus Time

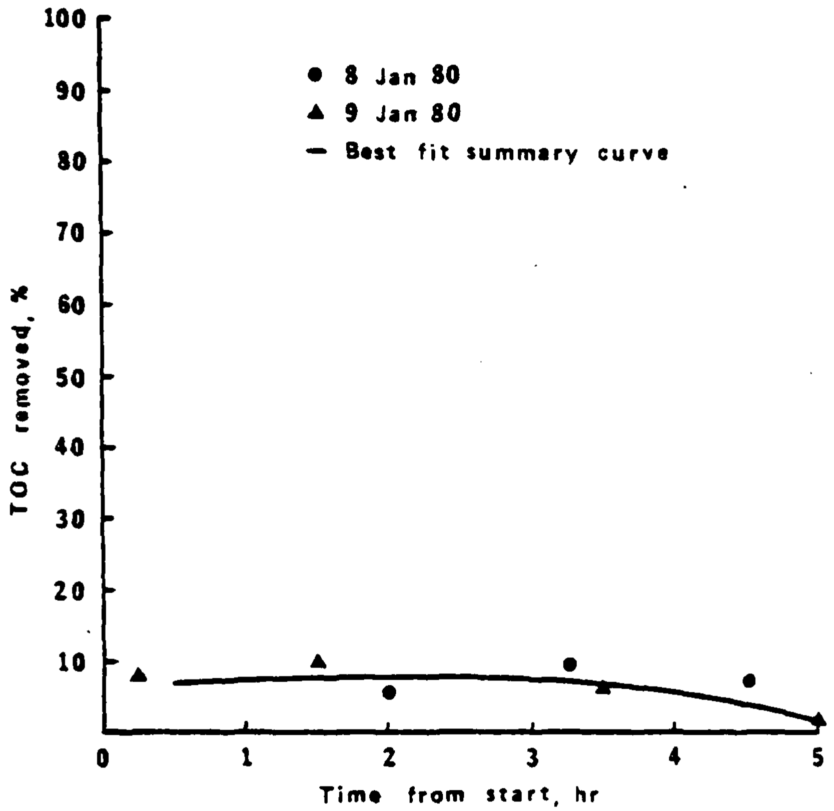


Figure 6: - TOC Removed from a Mixture of Detergent and Secondary Effluent by Filtration Through Filter 2 Versus Time

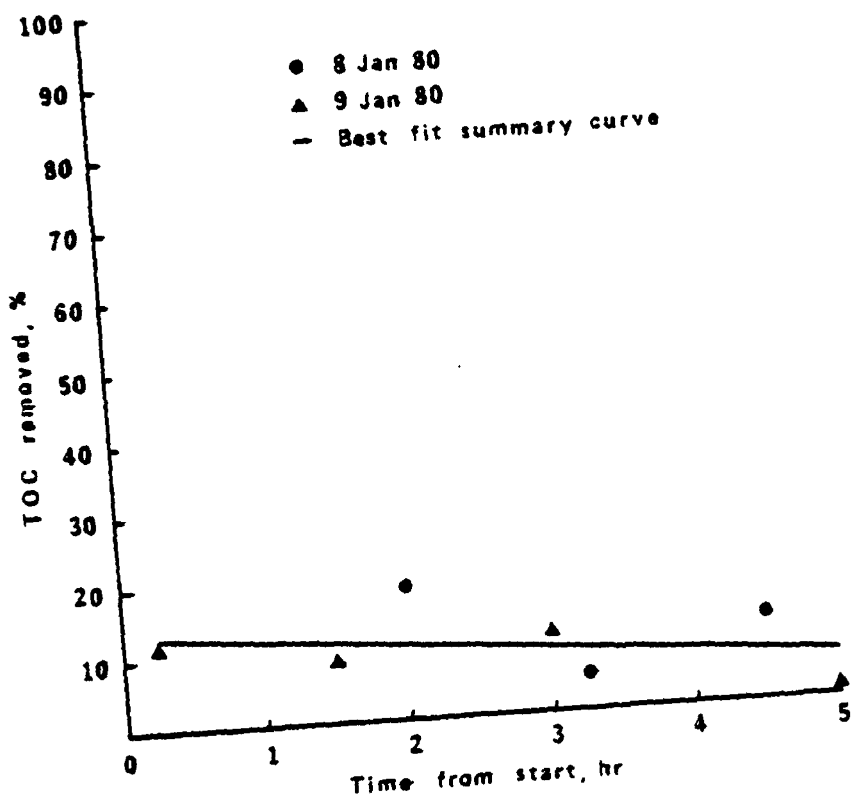


Figure 7: TOC Removed from a Mixture of Detergent and Secondary Effluent by Filtration Through Filter 3 Versus Time

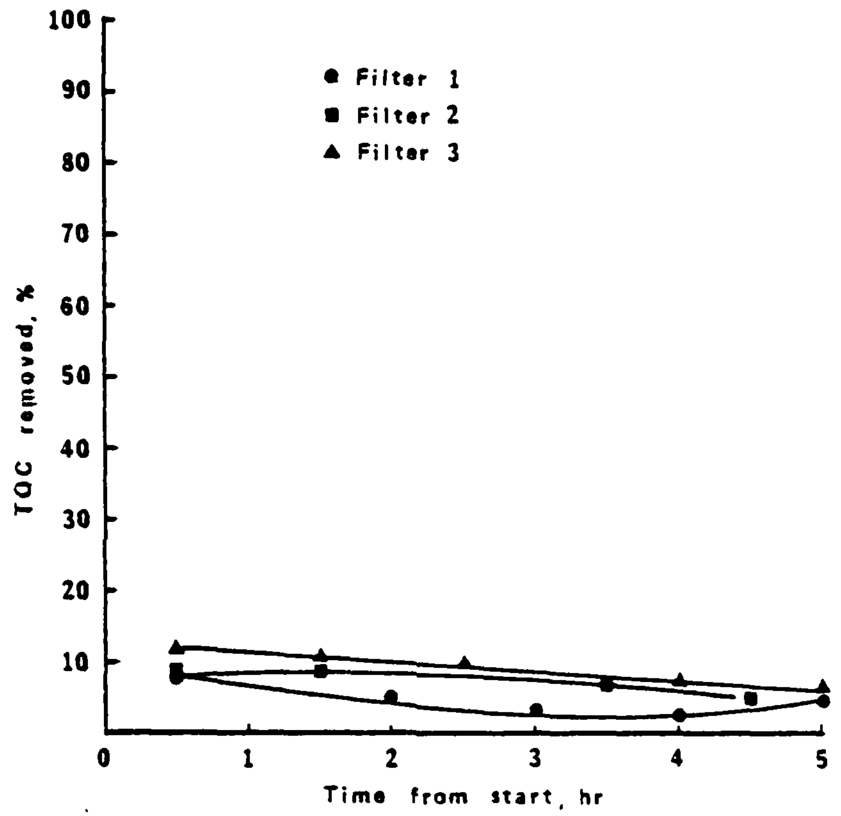


Figure 8: A Composite of the Summary Curves for Filters 1, 2, and 3 for TOC Removed from a Mixture of Detergent and Secondary Effluent Versus Time

times. The results are presented in Table 4. Graphical representations of the results for filters 1, 2 and 3 are given in Figures 9, 10 and 11. A composite of the summary curves is shown in Figure 12.

From the summary curves given in Figure 12, the pattern of removal can be characterized as follows. An aging process takes place in each filter during the initial hours of operation. During this time the grease is making direct contact with the medium and is being removed. The direct contact continues until the medium is coated and no further direct medium to grease particle contact is possible. At this point the removal rate begins to decrease.

This general pattern is repeated in the results obtained for each filter. In filters 1 and 2 (see Figures 9 and 10) the aging process was gradual, requiring 1 - 1/2 hours to reach a maximum. This process was much faster in filter 3. (see Figure 11) Also the magnitude of the peak reached in filter 3 was much greater than the maximums of filters 1 and 2. The greater magnitude and more rapid aging in filters 3 is probably due to the smaller medium size. More surface area is available so more contact and greater removal are possible. The grease particles are forced closer to the medium by the flow streamlines as the wastewater flows through the smaller pore spaces. The result of this pattern of flow is more direct contact earlier in the filtration process thereby enhancing the aging process as well as the magnitude of removal.

From the summary curves in Figure 12, it was concluded that the size of the medium has only a small effect upon the removal of grease from secondary effluent. Only during the earliest stages of the filtration process does the medium size exert an influence on the amount of grease removed. In the long run however, all of the sizes of medium tested in this study performed similarly.

TABLE 4: Percent TOC Removed by Varied Medium Sizes During Filtration at a Constant Flowrate

Date	Time from start, hr	TOC removed, % Filter 1	Filter 2	Filter 3
	0.50	8.4	11.3	7.2
3 Dec 79	1.50	26.7	20.9	16.5
	2.50	10.5	14.0	6.6
	4.50	5.9	10.7	13.8
	0.50	11.5	11.9	40.1
4 Dec 79	1.50	8.5	11.3	11.6
	2.75	---	17.9	10.1
	4.50	6.7	13.4	8.5
	0.25	11.5	20.7	22.0
5 Dec 79	1.50	21.5	23.2	15.4
	2.75	19.6	14.6	18.8
	4.25	21.7	18.5	11.5
	0.50	4.1	6.2	9.3
10 Jan 80	1.75	2.4	1.5	8.5
	3.00	2.1	3.4	2.8
	4.50	5.7	0.3	7.0

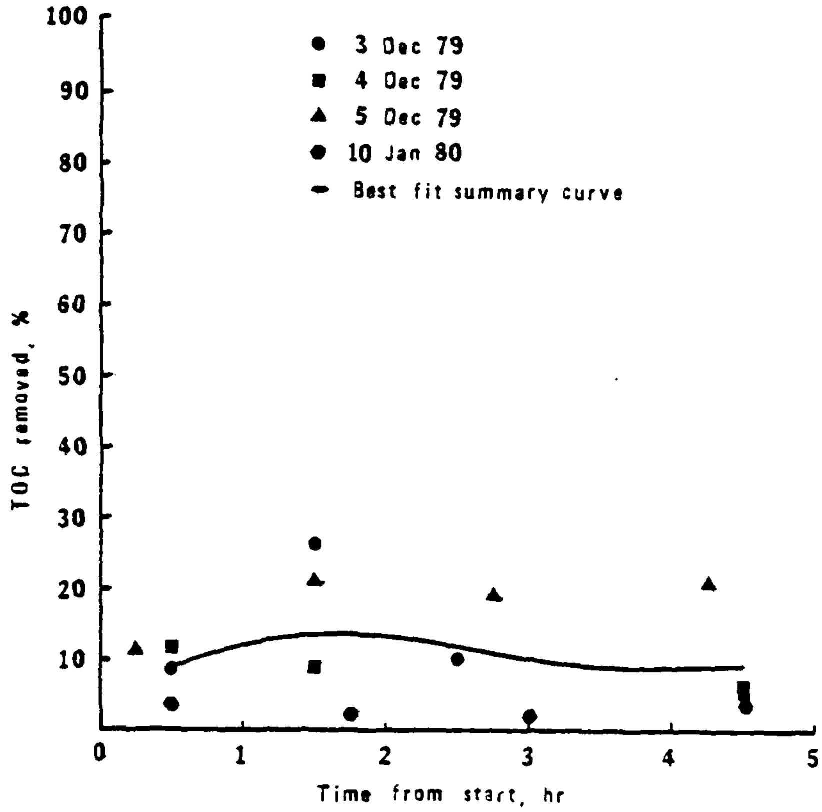


Figure 9: TOC Removed by Filtration Through 0.47 mm Sand at 5 gpm/ft^2 Versus Time

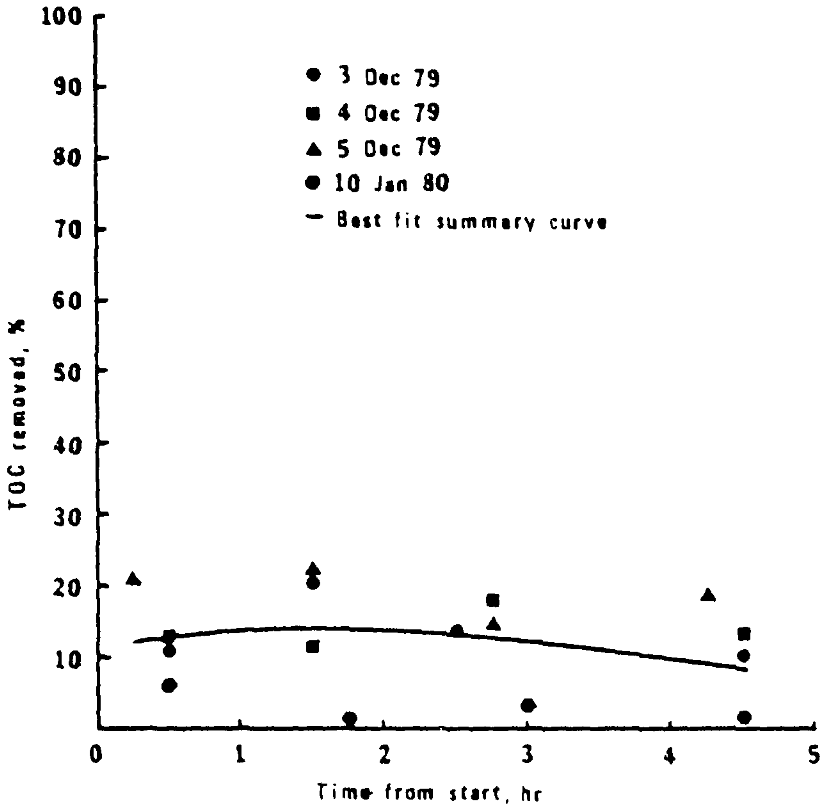


Figure 10: TOC Removed by Filtration Through 0.34 mm Sand at 5 gpm/ft^2 Versus Time (Filter 2)

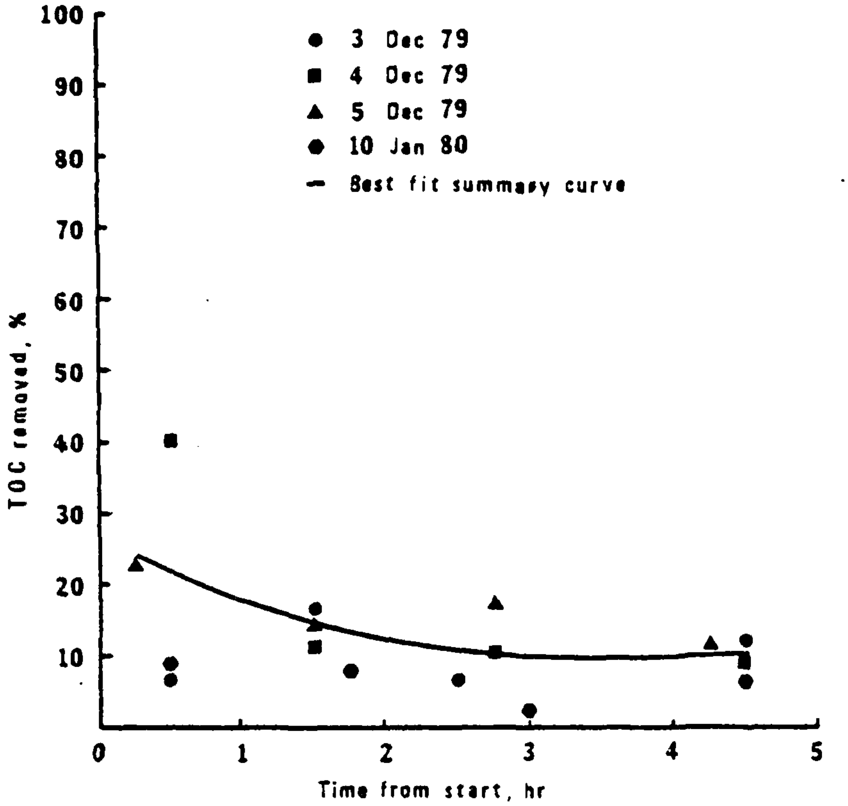


Figure 11: TOC Removed by Filtration Through 0.27 mm Sand at 5 gpm/ft^2 Versus Time (Filter 3)

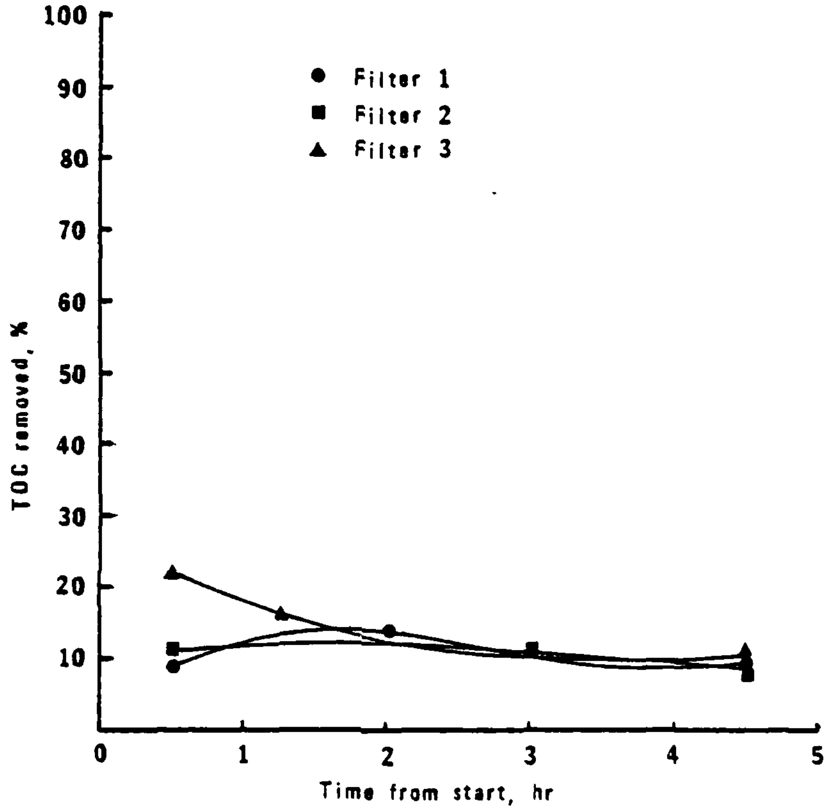


Figure 12: A Composite of the Summary Curves for Filters 1, 2 and 3 for TOC Removal by Filtration at a Constant Flowrate Versus Time

Determination of Optimum Filtration Flowrate

During this phase of the project a single medium size was selected and used in all three filters, but the flowrate to each filter was varied. The medium size selected after examining the results of the first phase of experimentation was 0.34 mm. The flowrates used in filters 1, 2, and 3, were 5.0, 2.5, and 1.2 gpm/ft^2 (203.7, 102.7, and 48.9 lpm/m^2) respectively. As in stage one, these experiments were repeated four times for consistancy and comparability. The results are presented in Table 5 and graphically in Figures 13, 14, 15 and 16.

The removal of grease from secondary effluent during these experiments follows a pattern similar to that observed in the studies dealing with the effects of medium size. After an initial aging process, there is a sharp decrease in the removal rate. Both the aging and the decrease occurred during the first 1-1/2 hours of operation. The reasons for the aging and the decrease have already been discussed.

Additionally, a slight increase in the amount of removal was detected at the end of each experiment. This increase is very slight and is probably related to the solids removal within the filter. As the solids are removed, they build up within the interstices of the medium. These solids offer additional contact sites for the grease. Upon contact with the solids, grease will be removed. The increase observed is evidence of this.

Review of the summary curves shown in Figure 14 leads to some interesting observations. As the flowrate decreases, the magnitude of the initial removals increase. This is a result of an increased opportunity for contact because the grease in the wastewater is in the filter bed for a longer period of time. Also as the flowrate decreases, the ability of the liquid to strip away grease particles which are already in contact with the medium decreases. As a result more grease remains attached to the medium. As observed while determining an

TABLE 5: **Percent TOC Removed by Varied Flowrates During Filtration With Constant Medium Size**

Date	Time from start, hr	TOC removed, % Filter 1	Filter 2	Filter 3
	0.25	1.3	8.5	79.2
5 Feb 80	1.50	4.2	1.1	4.0
	2.75	0.5	21.8	10.1
	4.50	8.2	6.1	10.3
	0.33	3.1	16.5	55.8
6 Feb 80	1.50	1.1	3.3	5.7
(am)	2.75	6.7	3.8	6.6
	4.50	2.9	0.8	6.1
	0.33	7.6	3.2	75.8
6 Feb 80	1.50	0.6	1.9	7.3
(pm)	2.75	1.0	1.1	5.6
	4.50	3.4	2.8	10.0
	0.50	5.7	9.1	55.0
7 Feb 80	1.50	2.5	2.1	6.4
	2.75	1.6	0.4	3.0
	4.50	2.4	1.1	3.6

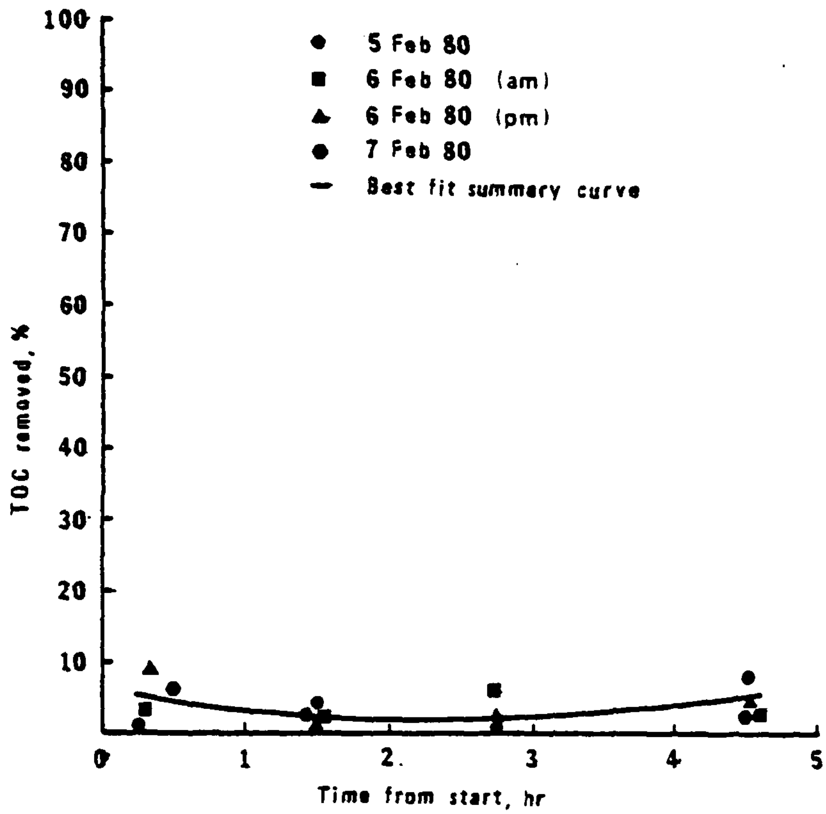


Figure 13: TOC Removed by Filtration at 5 gpm/ft^2 Through 0.34 mm Sand Versus Time (Filter 1)

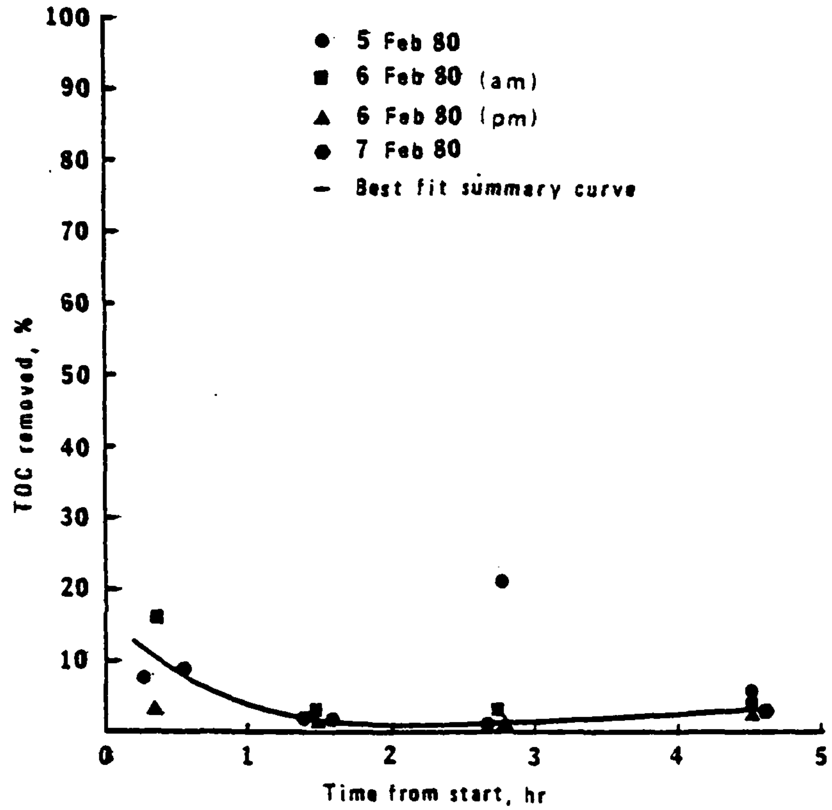


Figure 14: TOC Removed by Filtration at 2.5 gpm/ft^2 Through 0.34 mm Sand Versus Time (Filter 2)

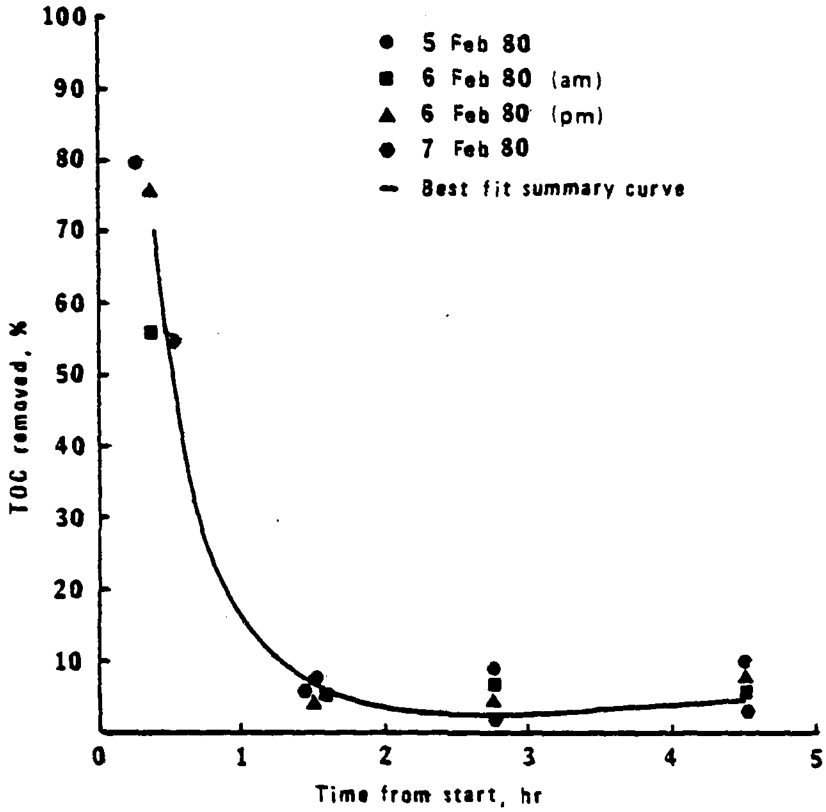


Figure 15: TOC Removed by Filtration at 1.2 gpm/ft^2 Through 0.34 mm Sand Versus Time (Filter 3)

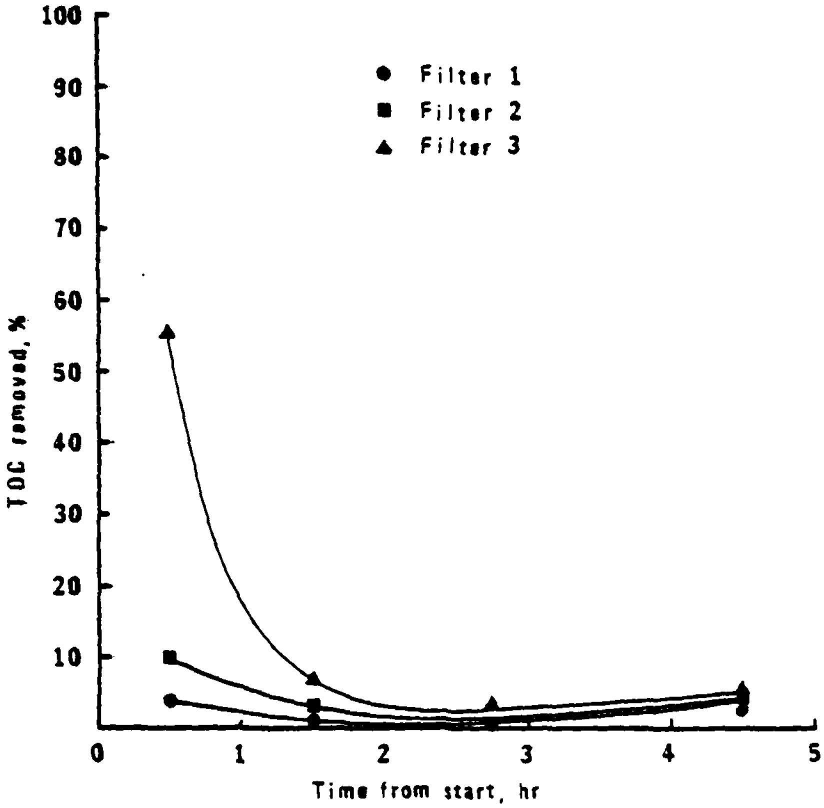


Figure 16: A Composite of the Summary Curves for Filters 1, 2, and 3 for TOC Removal by Filtration Through a Constant Medium

optimum medium size, after the initial aging process, the response of all of the filters becomes nearly identical.

It can be concluded that the filtration flowrate had little significant impact upon the removal of grease from the secondary effluents tested. Although larger amounts of grease are removed initially, the level of removal is not maintained.

Discussion of Results

Although the removal of ten percent of the grease present is low, it is reasonable for the experiments performed. Several factors, present during the testing, had effects which would alter the results.

Climate is a major factor in biological treatments. Young (28) found that treatment plants in cold regions produced effuents with significantly higher grease concentrations than plants in warm regions. Because the operation of most biological treatment processes is enhanced by warm weather, the amount of grease discharged in the effluent of treatment plants located in warm climates is usually low. As the amount of grease present decreases, it becomes increasingly difficult to remove. A similar problem is faced during biological treatment. Although it is possible to produce an effluent of pristine quality, the expense and operational difficulties introduced by trying to remove the last 5 mg/l of BOD are prohibitive. Similarly, the last 5 mg/l of grease is the most difficult to remove. Removal of grease from the effluents of the cold region plants by filtration should be more successful than in warm climates. The larger amounts of grease present would be removed more easily. Should the weather become cold enough to cause the grease to solidify, grease removal by filtration would be significant.

To enhance the amount of grease present in the effluent tested, oleic acid was introduced. Oleic acid was chosen because it is a very common fatty acid present in secondary effluents. However, fatty acids are not the predominant class of grease present in secondary effluent. Hydrocarbons, which tend to be of petroleum or mineral origin, are the predominant class. Unfortunately the identification of specific hydrocarbon compounds found in secondary effluents has not been accomplished, therefore the selection of a suitable hydrocarbon for use during the experiment was not possible. Based upon the experiences of members of the petroleum industry (2, 9, 10), as previously discussed, it is probable that hydrocarbons are more susceptible to granular filtration than are fatty acids.

It was necessary to emulsify the oleic acid with detergent to insure that it would mix with the secondary effluent. The addition of the detergent had a significant influence on the ability of the filter to remove organic carbon. The removal rates observed when the detergent was added (see Figure 8) are 50 percent less than those observed in the tests conducted without using the detergent. With this in mind, an actual removal of 20 percent would have been observed during the experiments conducted, it the detergent had not been used. (see Figure 4)

Recommendations for Further Study

The subject of grease removal from secondary effluent by granular filtration requires more study than that represented by the work reported here. There are several questions about grease removal by filtration which remain unanswered.

This study should be repeated using secondary effluents which have a naturally high grease content. This would eliminate any inaccuracies introduced through the use of the oleic acid and soap. Given the effects of climate, it

is unlikely that the grease removal ability of filters can be generalized. To obtain an accurate assessment of filter capabilities further studies should be conducted under all climatological conditions.

During this study, the effect of media size is not established clearly because the size range of the media tested is narrow. The removal of grease from secondary effluent is, to a large extent, a surface phenomenon. The ratio of surface areas (A_{max}/A_{min}) for the media is on the order of 3 to 1. Selection of a media size range, with an order of magnitude variation of A_{max}/A_{min} would more accurately establish the effect of media size on grease removal.

An investigation of where in a granular filter grease removal takes place would be of value. This could be accomplished by sampling throughout the depth of the filter bed. Analysis and comparison of these samples and the influent should yield answers to two questions: Is grease removed with the suspended solids in the first few inches of the filter? or, Is grease removed uniformly through the bed?

A study of the grease removal mechanisms would also be of value. It is not known if grease is removed by the same mechanisms which remov suspended particles. The results of such a study might point out ways to enchance the grease removal ability of granular filters.

Filter aids are often used to enhance the performance of granular filters. The effects of these filter aids upon grease removal are unknown. Perhaps a specific filter aid exists which would improve the ability of sand filters to remove grease from secondary effluent. Research in this subject area could be of value.

5. CONCLUSIONS

Conclusions derived from this study are:

1. The wet extraction technique for the measurement of grease in a liquid is an unsatisfactory method of analysis when working with secondary effluent.
2. Filter media, in the size range of 0.27 - 0.47 mm, have no significant impact upon the removal of low concentrations of grease (< 50 mg/l) from secondary effluent.
3. The size range of the media tested was relatively small and did not accurately establish the effect of media size on grease removal from secondary effluent.
4. Filtration flowrates, in the range of 1.2 - 5.0 gpm/ft^2 (48.9 - 203.7 lpm/m^2), have no significant impact upon the removal of low concentrations of grease (< 50 mg/l) from secondary effluent.
5. Sand filters utilizing medium or filtration flowrates in the ranges specified above are not very effective in the removal of low concentrations of grease (< 50 mg/l) from secondary effluent.
6. The removal of grease from wastewater by biological treatment is enhanced during warm weather.

6. ENGINEERING APPLICATIONS

Filtration is used extensively as a tertiary treatment process. In some instances, grease removal may represent one more positive effect of the use of filtration. Based upon the results of this study, the removal of grease by sand filters with a medium in the size range of 0.27 - 0.47 mm is limited. Appreciable grease removal should not be expected at wastewater treatment plants where the effluent has a low concentration of grease. However, a significant reduction in the effluent grease concentration may occur as a result of sand filtration at those plants where higher concentrations of grease may be present in the effluent.

7. SUMMARY

The presence of grease in the effluent of secondary wastewater treatment plants is a source of pollution. As such, its removal is desireable. The ability of sand filters, as used in tertiary treatment, to remove grease from secondary effluent is examined in this study.

A mixture of secondary effluent and oleic acid, which was added to enhance the grease content of the effluent, was filtered through three high pressure sand filters. During the first stage of the experiment the flowrate through the filters was held constant and the size of the medium was varied. During the second stage, the medium size was held constant and the flowrate was varied. Samples of the filter influent and effluent was taken and analyzed using a Total Organic Carbon analyzer.

It was concluded after analysis of the data, that neither medium size or filtration flowrate had a significant effect on the removal of grease in sand filters. Initial differences were noted, however after 1-1/2 hours of operation the removals observed were nearly identical, regardless of medium size or flowrate. After the initial differences, the grease removal was on the order of 10 percent or less.

The removal of grease, from secondary effluent with grease concentrations less than 50 mg/l, by filtration through a sand medium with a size range of 0.27 - 0.47 mm at flowrates ranging from 1.2 to 5.0 gpm/ft^2 (48.9 - 203.7 lpm/m^2) is limited. In such cases, the removal of 10 percent of the grease present can be expected. It is expected that the filtration of effluents with higher grease concentrations, such as those in cold weather regions, will be more successful.

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APPENDIXES

Appendix A:

PRELIMINARY TESTING

APPENDIX A PRELIMINARY TESTING

Several preliminary filtration tests were performed to insure that the apparatus and the analytical techniques to be used were adequate. The tests and their results are the subject of this Appendix.

The filter apparatus was set up and tested at the University of California at Davis Wastewater Treatment Plant. The filters were operated continuously with backwashing occurring a minimum of once every twenty four hours or when a headloss of 20 lb/in^2 or more was obtained. Samples of the filter influent and effluent were taken twice a day, corresponding to the peak flow periods in the treatment plant.

The results of liquid-liquid freon extractions performed on these samples were expected to help define the optimum medium size and flowrate, and any possible correlations between grease removal and solids removal. Unfortunately the results of these tests were inconclusive. Two reasons are offered for the results that were observed. First, that little or no grease was present in the effluent; and second, that a flaw existed in the analytical procedure. The analytical procedure was reviewed and found to be satisfactory.

In an attempt to find a plant effluent with more grease, the filters were moved to the Fairfield-Suisun Wastewater Treatment Plant. After one week of operation, results similar to those at UCD were obtained. Because of these preliminary tests it was decided to add grease to the secondary effluent before it entered the filters. Based on the characteristics of secondary effluent, as discussed earlier, oleic acid was chosen as a suitable grease compound.

It now became necessary to design an apparatus for the injection of the oleic acid into the secondary effluent. After some testing a chemical feed

pump made by Liquid Metronics, Inc. was judged satisfactory as an injection mechanism. Because of its insolubility in water, the oleic acid, in its pure form, could not be fed directly into the secondary effluent. To improve the complete mixing of the oleic acid and the secondary effluent, the oleic acid was emulsified using a commercial clothes washing detergent. The oleic acid and the detergent were mixed with water in a tank, and this mixture was metered by the feed pump into the secondary effluent.

To operate on a continuous basis, it was necessary to have 30 gallons of feed solution mixed on a daily basis. A 50 gallon tank was used to hold the mixture, and a high speed paddle stirrer was used to keep the mixture form separating.

After operating through the night, it was observed that a mat of solid white material had formed on the surface of the feed solution. Additionally small white solid particles were entering the filters, and were being removed during filtration. From the results of a freon extraction of the influent and effluent, an average grease removal rate of 85 percent was occurring. The conclusion was that the oleic acid, with a melting point of 14°C, was solidifying as the temperature dropped at night. As a result, continuous operation was no longer possible.

To select a suitable run length for the experiment, several factors were considered. Containers to hold the feed mixture were available in several sizes. Several were tested to determine which would hold enough feed solution, based on the rate of metering by the feed pump, to allow a reasonable filtration run. To keep the feed solution mixed a stirrer was required. The high speed paddle stirrer could only be used in the large tank. The only other stirrers available were magnetic stirrers. The capability of these stirrers limited the amount of feed solution which could be prepared and therefore affectd the length of the

filter run. Other considerations were the daily start up time and the time required for backwashing at the end of each run. After considering all of these factors a run length of 5 hours was chosen.

Appendix B:

SAMPLE CALCULATIONS

Sample Calculations

1. Calculation of the concentration of the oleic acid in the secondary effluent:

   a) Metering rate of Liquid Metronics pump:

   $$2.62\ \text{l/hr} = 0.044\ \text{l/min}$$

   b) Concentration of oleic acid in feed solution:

   $$\frac{25\ \text{gm}}{5\ \text{g}\ (3.785\ \text{l/g})} = 1.32\ \text{gm/l or } 1320\ \text{mg/l}$$

   c) Feed rate of oleic acid:

   $$0.044\ \text{l/min} \times 1320\ \text{mg/l} = 58.08\ \text{mg/min}$$

   d) Flowrate of secondary effluent:

   $$0.75\ \text{g/min} \times (3.785\ \text{l/g}) = 2.84\ \text{l/min}$$

   e) Concentration of oleic acid in secondary effluent:

   $$\frac{58.08\ \text{mg/min}}{2.84\ \text{l/min}} = 20.5\ \text{mg/l}$$

2. Filtration flowrate:

   a) Filter area

   $$\text{area} = \pi r^2 = \pi(1.5)^2 = 7.1\ \text{in}^2$$

   $$\frac{7.1\ \text{in}^2}{144\ \text{in}^2/\text{ft}^2} = 0.049\ \text{ft}^2$$

   $$0.049\ \text{ft}^2 \times 0.093\ \text{m}^2/\text{ft}^2 = 0.0045\ \text{m}^2$$

b) Flow through filter:

Consider filter 1 with a 0.25 gpm flow control

In english units the flow = 0.25 gpm

In metric units flow =

0.25 gpm x (3.785 l/g) = 0.95 l/min

c) Filtration flowrate:

In english units: $\frac{0.25 \text{ gpm}}{0.049 \text{ ft}^2} = 5.1 \text{ gpm/ft}^2$

In metric units: $\frac{0.95 \text{ l/min}}{0.0046 \text{ m}^2} = 203.7 \text{ lpm/m}^2$

3. Percent TOC removed:

Experimental data for 5 Dec 79 @ 0.25 hrs

TOC of the influent = 29.4 mg/l

TOC of the effluent = 26.0 mg/l

Percent TOC removed:

$$\frac{29.4 - 26.0}{29.4} \times 100 = 11.5 \%$$

Appendix C:

SIEVE ANALYSIS

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

SIEVE ANALYSIS

SAMPLE NO. 1

DATE 31 July 79

LOCATION U. C. Davis

TECHNICIAN K. Schaefer, T. Calezewski, M. Matsumoto

DEPTH

DESCRIPTION OF SOIL Blended Sand

SIEVE NO	SIEVE OPENING (mm)	WT SIEVE (g)	WT SIEVE + SOIL (g)	WT SOIL RETAINED (g)	CUMULATIVE WT RETAINED (g)	TOTAL WT FINER THAN (g)	% FINER THAN	% FINER THAN BASIC ORIGINAL SAMPLE
20	0.841	416	435	19	19	237	92.6	
30	0.600	410	589	179	198	58	22.6	
35	0.500	552	577	25	223	33	12.8	
40	0.420	455	477	22	245	11	4.5	
50	0.297	388	399	11	256	0	0	
60	0.250	358	358	0	256	---	---	
Pan	---	375	375	0	256	---	---	

% FINER THAN BASIC ORIGINAL SAMPLE = $\frac{W_{finer} + w_f}{W_{+200} + w_f}$ COEFFICIENT OF UNIFORMITY (C_u) = $\frac{D_{60}}{D_{10}}$

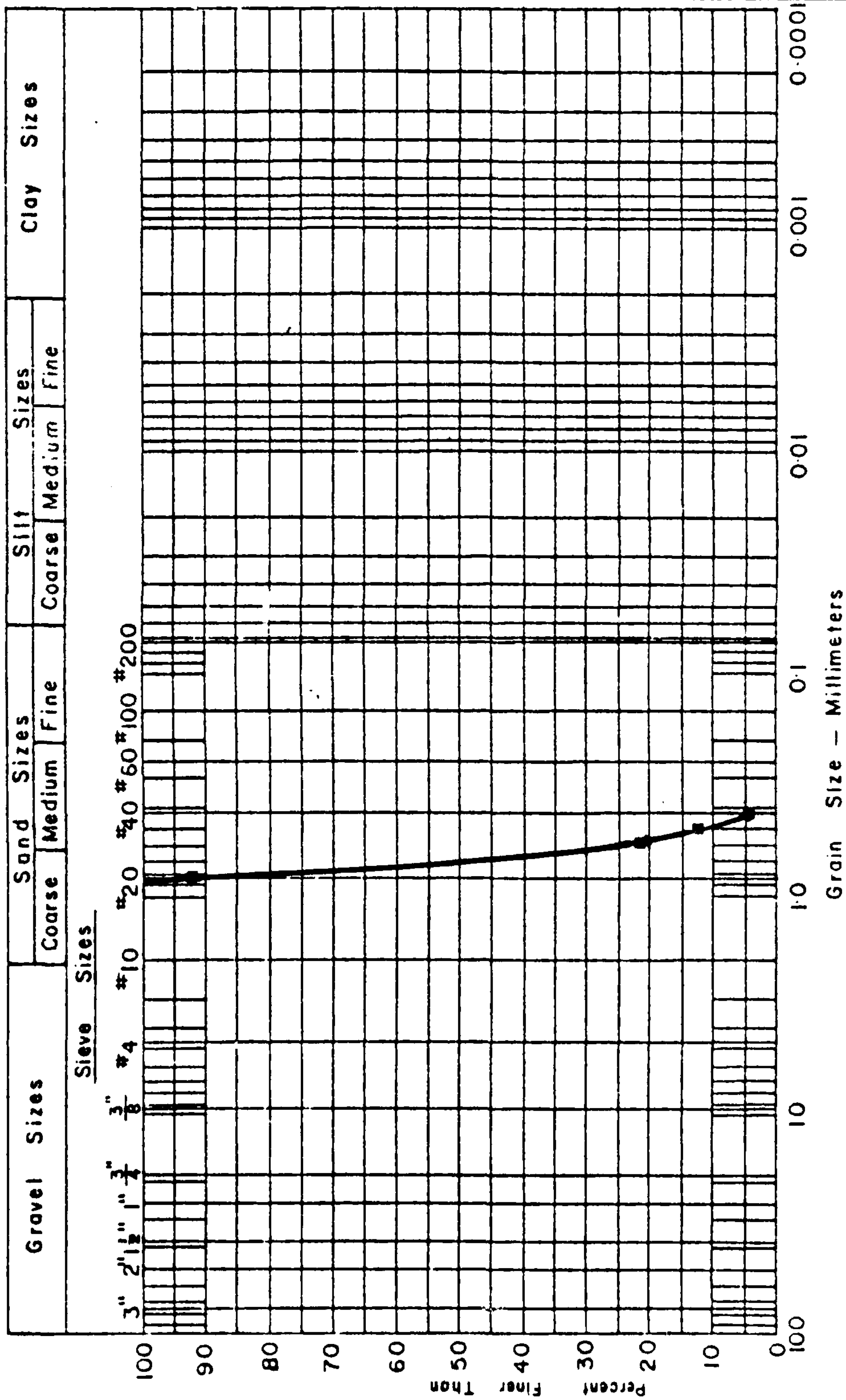
TOTAL WT OF SOIL 256 (g) WT OF FINES (w_f) ______ (g) TIME OF SIEVING 10 (min)

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE

LAB ORDER	
PROJECT K Schaefer Thesis	
SAMPLE 1	
LOCATION UC Davis	
HOLE	DEPTH
TECHNICIAN KAS	DATE 31 July 79



D_{10} = 0.425 mm

D_{60} = 0.70 mm

C_u 1.47

Remarks: Blended Lone Star filter sand

Note: M.I.T Grain Size Scale

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

SIEVE ANALYSIS

SAMPLE NO 2
LOCATION U. C. Davis
DEPTH
DESCRIPTION OF SOIL Blended Sand

DATE 31 July 79
TECHNICIAN K. Schaefer, T. Galezewski
M. Matsumoto

SIEVE NO	SIEVE OPENING (mm)	WT SIEVE (g)	WT. SIEVE + SOIL (g)	WT. SOIL RETAINED (g)	CUMULATIVE WT RETAINED (g)	TOTAL WT FINER THAN (g)	% FINER THAN	% FINER THAN BASIC ORIGINAL SAMPLE
20	0.841	416	419	3	3	249	98.8	
30	0.600	411	455	44	47	205	81.3	
35	0.500	552	590	38	85	167	66.3	
40	0.420	455	537	82	167	85	33.7	
50	0.297	388	470	82	249	3	1.2	
60	0.250	357	360	3	252	0	0	
fan	---	375	376	1	253	---	---	

% FINER THAN BASIC ORIGINAL SAMPLE = $\frac{W_{finer} + w_f}{W_{+200} + w_f}$ COEFFICIENT OF UNIFORMITY (C_u) = $\frac{D_{60}}{D_{10}}$

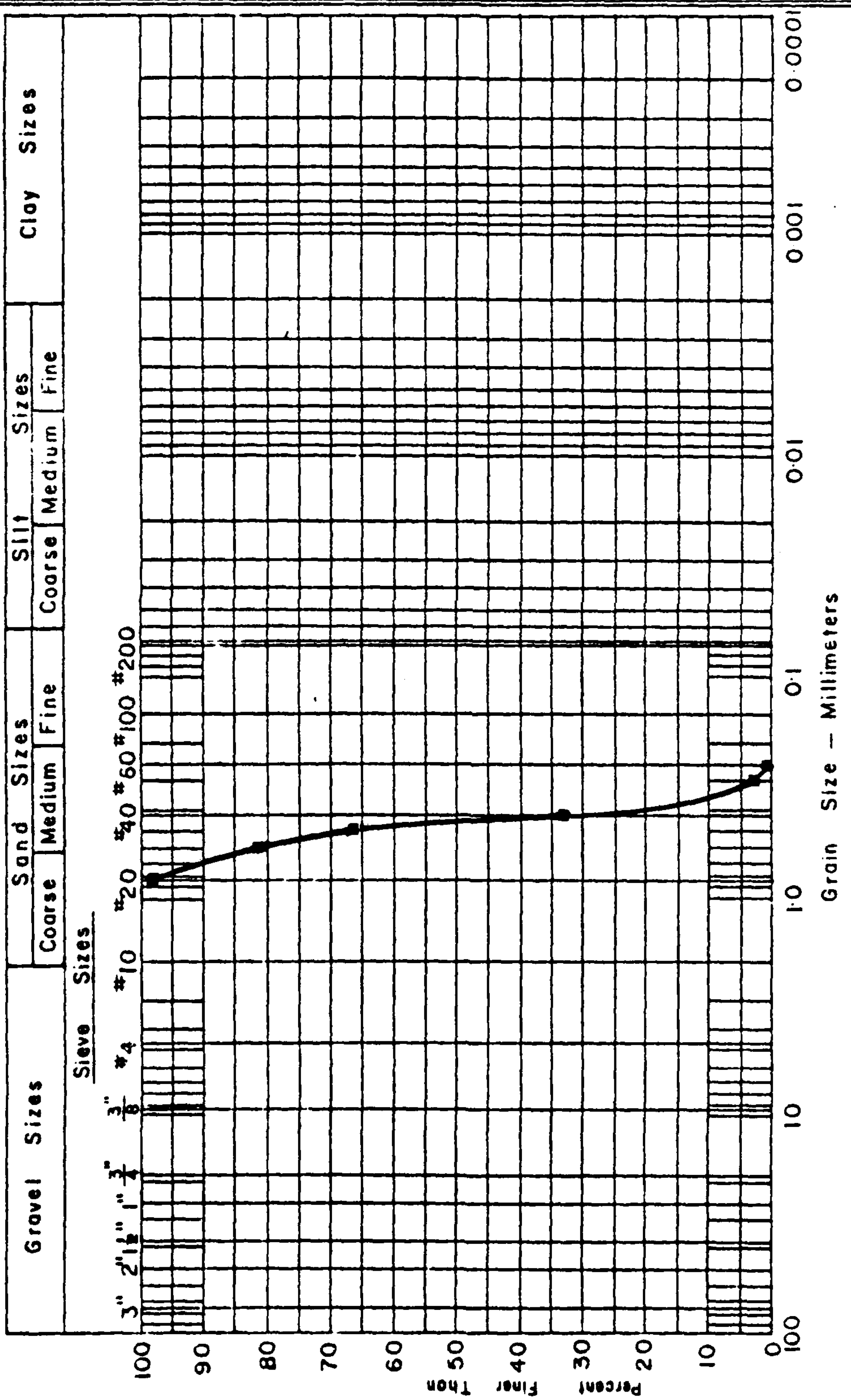
TOTAL WT OF SOIL 253 (g) WT OF FINES (w_f) ____ (g) TIME OF SIEVING 10 (min)

LAB ORDER
PROJECT K. Schaefer Thesis
SAMPLE 2
LOCATION [illegible] Davis
HOLE DEPTH
TECHNICIAN [illegible] DATE 31 July 79

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE



D_{10} = 0.35 mm
D_{60} = 0.49 mm
C_u 1.4

Remarks: Blended Lone Star filter sand

Note: M.I.T Grain Size Scale

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

SIEVE ANALYSIS

SAMPLE NO 3 DATE 23 Jan 80

LOCATION U. C. Davis TECHNICIAN K. Schaefer

DEPTH

DESCRIPTION OF SOIL Blended Sand

SIEVE NO	SIEVE OPENING (mm)	WT SIEVE (g)	WT. SIEVE + SOIL (g)	WT SOIL RETAINED (g)	CUMULATIVE WT RETAINED (g)	TOTAL WT FINER THAN (g)	% FINER THAN	% FINER THAN BASIC ORIGINAL SAMPLE
30	0.600	410	411	1	1	599	99.8	
40	0.420	454	468	14	15	584	97.5	
50	0.297	387	882	495	510	89	15.0	
60	0.250	357	384	27	537	62	10.5	
80	0.177	424	480	56	593	6	1.1	
100	0.149	359	364	5	598	1	0.3	
Pan	---	330	332	2	600	0	---	

% FINER THAN BASIC ORIGINAL SAMPLE = $\frac{W_{finer} + w_f}{W_{+200} + w_f}$ COEFFICIENT OF UNIFORMITY $(C_u) = \frac{D_{60}}{D_{10}}$

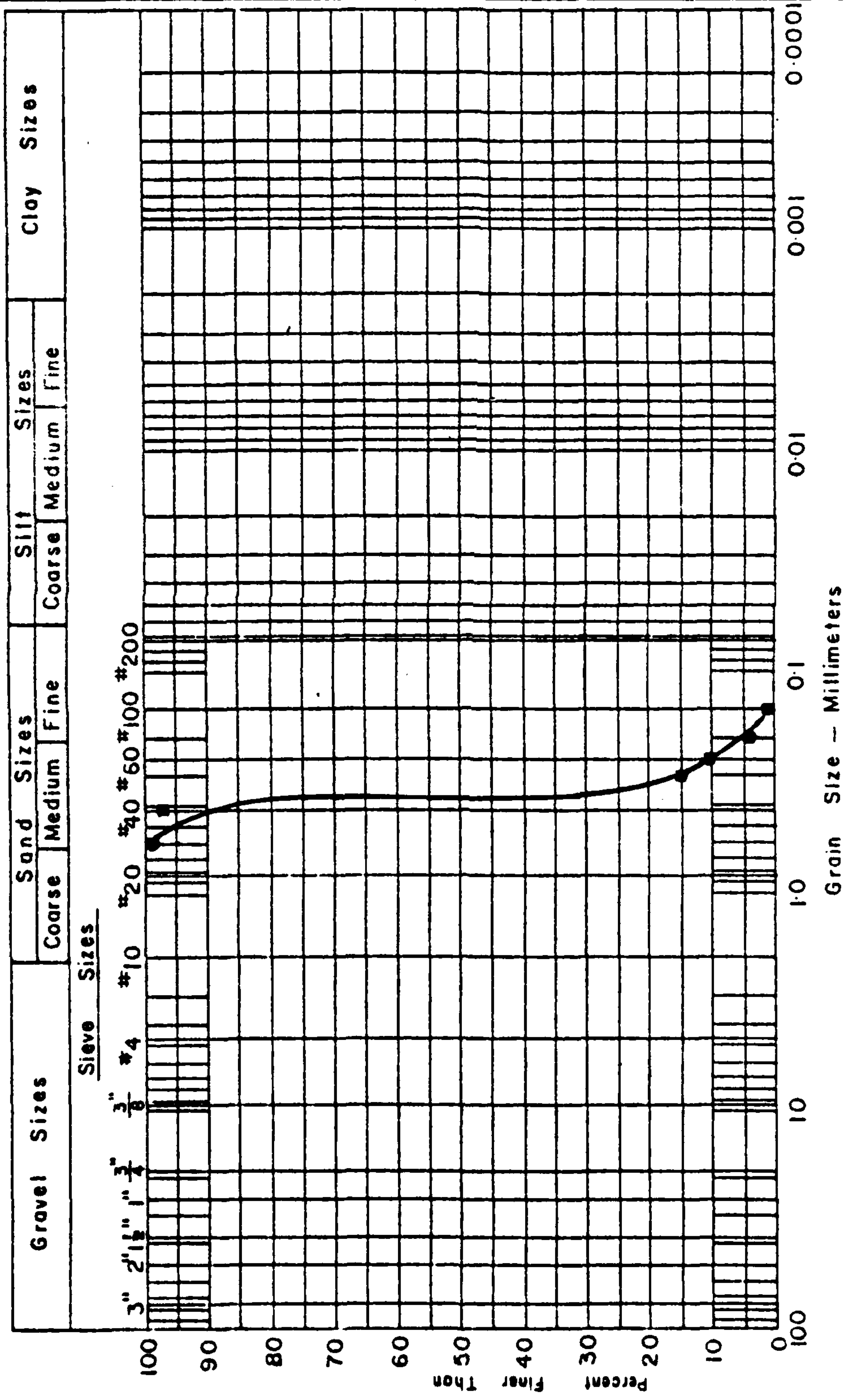
TOTAL WT OF SOIL 600 (g) WT OF FINES (w_f) ______ (g) TIME OF SIEVING 10 (min)

DEPARTMENT OF CIVIL ENGINEERING

SOIL MECHANICS LABORATORY

GRAIN SIZE CURVE

LAB. ORDER	
PROJECT K. Schaefer Thesis	
SAMPLE 3	
LOCATION UC Davis	
HOLE	DEPTH
TECHNICIAN KAS	DATE 23 Jan 80



D_{10} = 0.25 mm

D_{60} = 0.35 mm

C_u = 1.3

Remarks: Blended Lone Star filter sand

Note: M.I.T Grain Size Scale

Appendix D:

EXPERIMENTAL DATA

TABLE D-1: Experimental Data for the Filtration of Secondary Effluent

Filter	Date	Time from start (hr)	TOC, mg/l Influent (a)	Influent (b)	Influent Avg	Effluent (c)	Effluent (d)	Effluent Avg	TOC removed, %
1	8 Dec 79	1.5	7.6	6.8	7.2	6.5	6.4	6.45	10.4
		2.75	6.7	6.7	6.7	5.5	5.0	5.25	21.6
		5.0	5.7	5.9	5.8	5.2	4.4	4.8	17.2
2	8 Dec 79	1.5	9.6	9.7	9.65	8.0	8.1	8.05	16.5
		2.75	5.6	5.4	5.5	5.2	5.5	5.35	3.0
		5.0	7.0	6.5	6.75	5.2	5.4	5.3	21.5
3	8 Dec 79	1.5	7.9	8.1	8.0	7.5	6.4	6.9	13.1
		2.75	5.3	4.7	5.0	3.8	4.8	4.4	12.0
		5.0	5.2	5.2	5.2	4.7	4.8	4.75	8.6

TABLE D-2: Experimental Data for Filter 1 During the Filtration of a Mixture of Secondary Effluent and Detergent (0.47 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l						TOC removed, %
		Influent			Effluent			
		(a)	(b)	avg	(c)	(d)	avg	
8 Jan 80	2.0	14.8	14.1	14.45	13.8	13.4	13.6	5.8
	3.25	15.1	14.8	14.95	15.0	14.0	14.5	3.0
	4.5	15.4	14.6	15.0	13.5	14.1	13.8	8.0
9 Jan 80	0.25	14.3	13.2	13.75	12.4	12.3	12.35	10.2
	1.5	16.0	16.3	16.15	15.3	15.3	15.3	5.2
	3.0	15.0	15.2	15.1	14.4	14.3	14.35	4.9
	5.0	17.2	17.4	17.3	16.8	17.0	16.9	2.3

TABLE D-3: Experimental Data for Filter 2 During the Filtration of a Mixture of Secondary Effluent and Detergent (0.34 mm sand, 5.0 gpm/ft²)

Date	Time from start, hr	TOC, mg/l: Influent (a)	Influent (b)	Influent avg	Effluent (c)	Effluent (d)	Effluent avg	TOC removed, %
8 Jan 80	2.0	14.1	13.7	13.9	13.1	13.1	13.1	5.7
	3.25	15.3	15.0	15.15	13.8	13.5	13.65	9.9
	4.5	14.8	14.4	14.6	13.9	13.1	13.5	7.5
9 Jan 80	0.25	13.8	12.6	13.2	12.4	11.6	12.0	8.3
	1.5	15.6	15.6	15.6	13.7	14.4	14.05	9.9
	3.0	16.0	14.9	15.55	14.4	15.0	14.7	6.1
	5.0	17.2	16.8	17.0	16.8	16.4	16.6	2.3

TABLE D-4: Experimental Data for Filter 3 During the Filtration of a Mixture of Secondary Effluent and Detergent (0.27 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l						TOC removed, %
		Influent			Effluent			
		(a)	(b)	avg	(c)	(d)	avg	
8 Jan 80	2.0	18.5	18.4	18.45	14.8	15.1	14.95	18.9
	3.25	14.5	14.7	14.6	13.9	13.7	13.8	5.5
	4.5	14.8	15.5	15.1	13.5	13.2	13.3	11.9
9 Jan 80	0.25	12.9	12.9	12.9	11.1	11.5	11.3	12.4
	1.5	15.9	15.3	15.6	14.6	13.8	14.2	8.9
	3.0	16.4	16.0	16.2	14.6	14.2	14.4	11.1
	5.0	17.1	16.5	16.8	16.6	16.5	16.55	1.4

TABLE D-5: Experimental Data for Filter 1 During the Grease Removal Studies (0.47 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l						TOC removed, %
		Influent			Effluent			
		(a)	(b)	avg	(c)	(d)	avg	
3 Dec 79	0.5	32.9	33.6	33.25	30.7	30.2	30.45	8.4
	1.5	37.8	39.3	38.55	27.7	28.8	28.25	26.7
	2.5	34.5	35.0	34.75	31.7	30.5	31.1	10.5
	4.5	36.8	36.6	36.7	33.6	34.6	34.1	5.9
4 Dec 79	0.5	38.6	38.4	38.5	34.2	33.9	34.05	11.5
	1.5	33.9	33.2	33.55	31.1	30.3	30.7	8.5
	2.75							
	4.5	40.1	40.6	40.35	37.5	37.8	37.65	6.7
5 Dec 79	0.25	29.7	29.1	29.4	26.0	26.0	26.0	11.5
	1.5	25.9	26.1	26.0	20.5	20.3	20.4	21.5
	2.75	49.1	48.7	48.9	39.6	40.2	39.9	19.6
	4.25	37.6	37.3	37.45	29.1	29.5	29.3	21.7
10 Jan 80	0.5	26.5	26.7	26.6	25.4	25.6	25.5	4.1
	1.75	23.1	23.1	23.1	22.7	22.4	22.55	2.4
	3.0	27.7	27.8	27.75	27.4	26.9	27.15	2.1
	4.5	30.0	31.3	30.65	28.9	---	28.9	5.7

TABLE D-6: Experimental Data for Filter 2 During the Grease Removal Studies (0.34 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l Influent (a)	(b)	avg	Effluent (c)	(d)	avg	TOC removed, %
3 Dec 79	0.5	33.6	32.7	33.15	29.5	29.3	29.4	11.3
	1.5	35.5	35.3	35.4	28.1	27.9	28.0	20.9
	2.5	34.2	34.9	34.55	29.9	29.5	29.7	14.0
	4.5	38.4	38.7	38.55	34.6	34.2	34.4	10.7
4 Dec 79	0.5	34.6	34.6	34.6	30.7	30.2	30.45	11.9
	1.5	33.8	33.3	33.55	30.3	29.2	29.75	11.3
	2.75	38.0	38.4	38.2	31.5	31.2	31.35	17.9
	4.5	39.6	39.6	39.6	34.4	34.2	34.3	13.4
5 Dec 79	0.25	32.1	32.2	32.15	25.1	25.1	25.1	20.7
	1.5	28.0	28.7	28.35	21.5	22.0	21.75	23.4
	2.75	37.2	36.8	37.0	31.6	31.6	31.6	14.6
	4.25	38.7	40.2	39.45	33.2	31.1	32.15	18.5
10 Jan 80	0.5	26.5	24.8	25.65	24.8	23.3	24.05	6.2
	1.75	22.8	22.3	22.55	22.3	22.1	22.2	1.5
	3.0	27.3	28.4	27.85	26.5	27.3	26.9	3.4
	4.5	29.7	29.2	29.45	29.7	29.0	29.35	0.3

TABLE D-7: Experimental Data for Filter 3 During the Grease Removal Studies (0.27 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l						TOC removed, %
		Influent			Effluent			
		(a)	(b)	avg	(c)	(d)	avg	
3 Dec 79	0.5	33.7	34.1	33.9	31.1	31.8	31.45	7.2
	1.5	36.7	35.2	35.95	31.1	28.9	30.55	16.5
	2.5	38.4	39.5	38.9	36.4	36.2	36.3	6.6
	4.5	37.6	37.5	37.55	32.7	32.0	32.35	13.8
4 Dec 79	0.5	27.5	27.1	27.3	16.5	16.2	16.35	40.1
	1.5	32.4	33.0	32.7	28.9	28.9	28.9	11.6
	2.75	35.9	36.2	36.05	32.7	32.1	32.4	10.0
	4.5	41.5	42.2	41.85	37.9	38.7	38.3	8.5
5 Dec 79	0.25	25.3	25.1	25.2	20.1	19.2	19.65	22.0
	1.5	27.6	26.2	26.9	22.7	22.8	22.75	15.4
	2.75	37.2	38.2	37.7	30.7	30.5	30.6	18.8
	4.25	36.8	37.6	37.2	33.7	32.1	32.9	11.5
10 Jan 80	0.5	25.5	27.9	26.7	24.3	24.1	24.2	9.3
	1.75	24.3	24.1	24.2	22.0	22.3	22.15	8.5
	3.0	27.3	27.1	27.2	26.7	26.2	26.45	2.75
	4.5	31.7	30.6	31.15	28.7	29.2	28.95	7.0

TABLE D-8: Experimental Data for Filter 1 During the Grease Removal Studies (0.34 mm sand, 5.0 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l Influent (a)	(b)	avg	Effluent (c)	(d)	avg	TOC removed, %
5 Feb 80	0.25	42.2	41.9	42.05	42.2	40.8	41.5	1.3
	1.5	37.7	37.2	37.45	35.1	36.3	35.7	4.2
	2.75	40.0	39.6	39.8	38.5	40.7	39.6	0.5
	4.5	41.2	42.6	41.9	38.3	38.6	38.45	8.2
6 Feb 80 (am)	0.33	50.3	51.1	50.7	48.9	49.3	49.1	3.1
	1.5	50.7	49.4	50.05	49.3	49.7	49.5	1.1
	2.75	55.0	54.7	54.85	51.0	51.3	51.15	6.7
	4.5	53.7	53.5	53.6	51.5	52.5	52.0	2.9
6 Feb 80 (pm)	0.33	42.5	43.8	43.15	39.2	40.5	39.85	7.6
	1.5	50.6	50.1	50.35	49.9	50.2	50.05	0.6
	2.75	53.7	55.4	54.55	54.0	54.0	54.0	1.0
	4.5	61.0	60.8	60.9	58.4	59.2	58.8	3.4
7 Feb 80	0.5	41.1	42.2	41.65	39.3	39.2	39.25	5.7
	1.5	42.5	42.8	42.65	41.3	41.9	41.6	2.5
	2.75	46.5	46.7	46.6	45.7	46.0	45.85	1.6
	4.5	58.8	58.5	58.65	57.1	57.4	57.25	2.4

TABLE D-9: Experimental Data for Filter 2 During the Grease Removal Studies (0.34 mm sand, 2.5 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l Influent (a)	(b)	avg	Effluent (c)	(d)	avg	TOC removed, %
5 Feb 80	0.25	39.0	40.9	39.95	36.3	36.8	36.55	8.5
	1.5	36.2	35.9	36.05	35.2	36.1	35.65	1.1
	2.75	47.6	46.9	47.25	36.5	37.4	36.95	21.8
	4.5	38.2	39.1	38.65	35.7	36.9	39.3	6.1
6 Feb 80 (am)	0.33	48.5	46.0	47.25	39.7	39.2	39.45	16.5
	1.5	51.5	50.9	51.2	48.1	49.0	48.55	3.3
	2.75	52.7	52.6	52.65	50.8	50.5	50.65	3.8
	4.5	48.5	48.9	48.7	47.9	48.7	48.3	0.8
6 Feb 80	0.33	36.5	37.3	36.9	35.8	35.6	35.7	3.2
	1.5	48.8	49.2	49.0	48.0	48.1	48.05	1.9
	2.75	51.0	50.4	50.7	49.7	50.6	50.15	1.1
	4.5	58.3	57.8	58.05	56.6	56.2	56.4	2.8
7 Feb 80	0.5	40.3	38.6	39.45	35.9	35.8	35.85	9.1
	1.5	39.9	39.7	39.8	39.2	38.7	38.95	2.1
	2.75	42.7	42.5	42.6	42.4	42.4	42.4	0.4
	4.5	55.1	54.1	54.6	53.8	54.2	54.0	1.1

TABLE D-10: Experimental Data for Filter 3 During the Grease Removal Studies (0.34 mm sand, 1.2 gpm/ft^2)

Date	Time from start, hr	TOC, mg/l Influent (a)	(b)	avg	Effluent (c)	(d)	avg	TOC removed, %
5 Feb 80	0.25	18.0	18.5	18.25	3.5	4.1	3.8	79.2
	1.5	34.9	34.9	34.9	33.1	33.9	33.5	4.0
	2.75	38.5	38.3	38.4	34.2	34.8	34.5	10.1
	4.5	41.2	41.1	41.15	37.5	36.3	36.9	10.3
6 Feb 80	0.33	23.5	23.8	23.65	11.1	9.8	10.45	55.8
(am)	1.5	44.6	45.1	44.85	42.3	---	42.3	5.7
	2.75	50.2	50.7	50.45	47.2	47.0	47.1	6.6
	4.5	48.8	51.0	49.9	46.8	46.9	46.85	6.1
6 Feb 80	0.33	17.1	17.2	17.15	4.2	4.1	4.15	75.8
(pm)	1.5	45.8	45.8	45.8	42.3	42.6	42.45	7.3
	2.75	49.0	48.4	48.7	46.0	45.9	45.95	5.6
	4.5	57.3	57.3	57.3	51.7	51.4	51.55	10.0
7 Feb 80	0.5	31.0	30.1	30.55	13.6	13.9	13.75	55.0
	1.5	38.5	38.5	38.5	36.2	35.9	36.05	6.4
	2.75	39.8	39.5	39.65	39.3	38.6	38.45	3.0
	4.5	49.2	50.6	49.9	47.8	48.4	48.1	3.6